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THE JANUARY SCIENTIFIC MONTHLY

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SEARCHING OUT PLUTO—LOWELL'S TRANS-NEPTUNIAN PLANET X. ROGER LOWELL PUTNAM and DR. V. M. SLIPHER 5

THE NATURE OF METALS IN RELATION TO THEIR PROPERTIES. EARLE E. SCHUMACHER 22

SOME LESS WELL-KNOWN LEAD PIGMENTS. DR. A. H. SABIN 31

BEYOND THE MILKY WAY. SIR JAMES H. JEANS 35

THE FUNDAMENTALS OF THE RELATIVITY THEORY. DR. MAX TALMEY 41

IN QUEST OF APOLLO'S SACRED WHITE MICE. CLYDE E. KEELER 48

BIOLOGY IN SHAKESPEARE. PROFESSOR D. F. FRASER-HARRIS 54

THE MENTALITY OF PRIMATES. PROFESSOR LESLIE A. WHITE 69

SCIENCE SERVICE RADIO TALKS:

THE PIPES OF PAN, OLD AND NEW. DR. DAYTON C. MILLER 73

LIQUID HELIUM. DR. H. C. DICKINSON 75

DID PREHISTORIC MEN LIVE IN THE MIDDLE WEST? DR. M. M. LEIGHTON 77

HOW A SPIDER CAUGHT AND DINED ON A SIX-INCH SNAKE. L. F. PINKUS 80

THE PROGRESS OF SCIENCE:

The New Orleans Meeting of the American Association for the Advancement of Science; The Centenary of Othniel Charles Marsh. PROFESSOR R. S. LULL 85

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THE SCIENTIFIC MONTHLY

JANUARY, 1932

SEARCHING OUT PLUTO—LOWELL'S TRANS-NEPTUNIAN PLANET X

By ROGER LOWELL PUTNAM and Dr. V. M. SLIPHER

LOWELL OBSERVATORY, FLAGSTAFF, ARIZONA

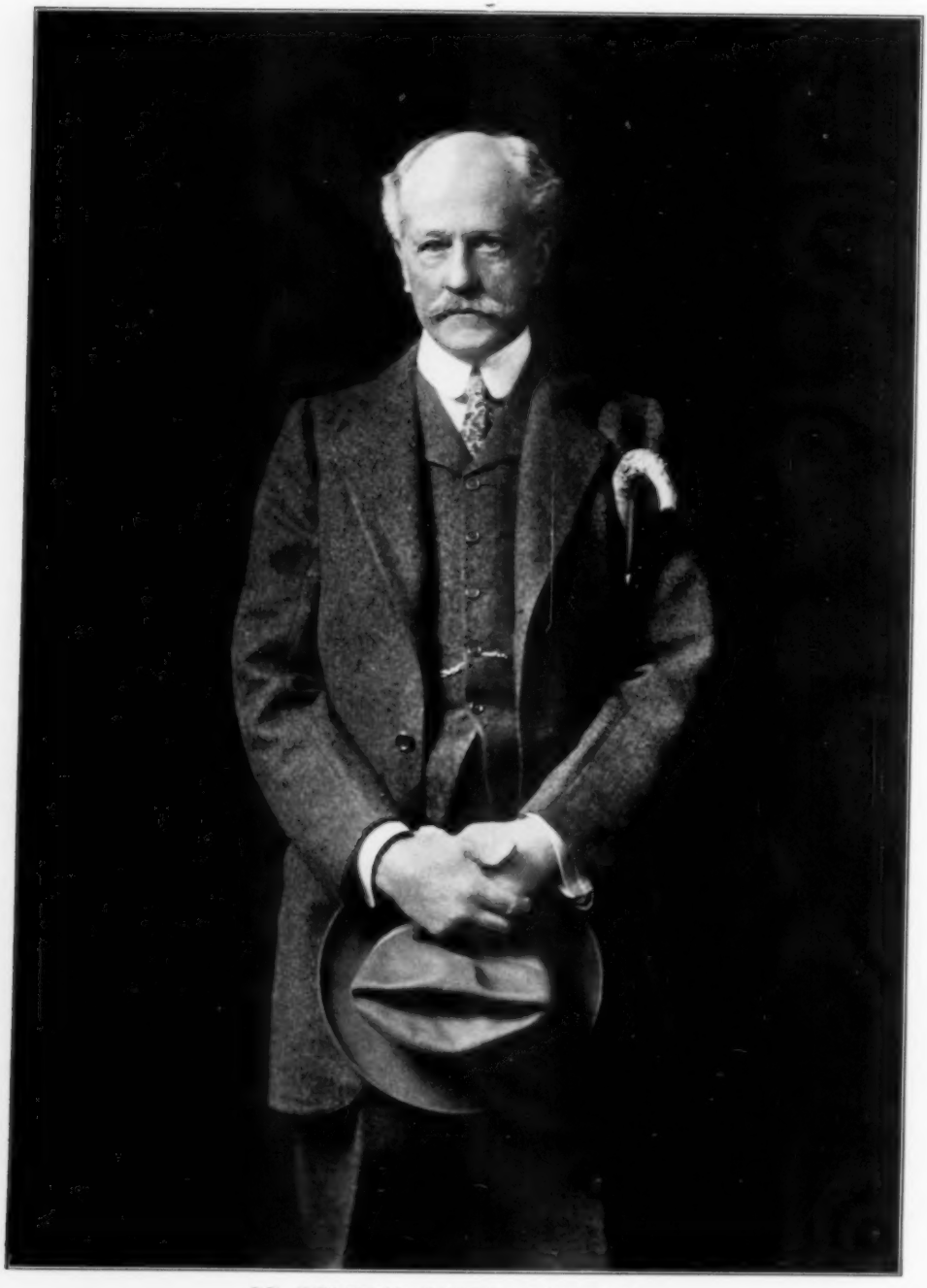
UNTIL the thirteenth of March, 1781, there had been only six known planets, including our own, and these had been known from time immemorial. Satellites of the major planets had been discovered, but to all intents and purposes the astronomical world thought that the solar system was complete.

On the night of March 13 of that year, however, Sir William Herschel, while patrolling the sky with his telescope, as was his habit, always alert to anything that might be seen, was struck by the appearance in the field of his instrument of an exceptional disk-like object. He at first thought that he had discovered a new comet, and, in fact, announced it as such, but it did not take many weeks' observation to show that it was a non-cometary body at great distance, and gradually he with others became persuaded that it was really a new planet that he had discovered. With rough calculations of the orbit, its course could be traced back, and it was found that it had actually been seen and its position had been plotted many times before, particularly by Lemonnier, but without its remarkable nature being recognized. These earlier positions with the new ones enabled a pretty exact orbit to be calculated.

Then after two thirds of a century came the remarkable discovery of Neptune, in 1846. Every one is now familiar with the work of Leverrier and Adams, who, starting with the then well-known fact that Uranus was deviating considerably from its computed orbit, quite independently calculated that clearly an outside planet must be disturbing it. They both almost simultaneously predicted where Neptune was to be found, and they have both received the credit, rather than Galle, who was first to observe it with the telescope.

At the beginning of this century, it began to be apparent that Neptune did not account for quite all the perturbations in the orbits of Uranus and Saturn. Various investigators attacked the problem, notable among whom was Dr. Percival Lowell, a great mathematician as well as a great astronomer, and this very difficult problem particularly appealed to him.

In his "Memoir on a Trans-Neptunian Planet," published in 1915, Dr. Lowell gave, in a little more than 100 pages and with little intimation of the years he had devoted to this difficult research, his results of the theoretical evidence of a planet beyond Neptune. This new member of the solar family he called Planet X. By way of introducing this subject, we can not do better than to quote some paragraphs from the beginning and the conclusion of his now classical Memoir:



DR. PERCIVAL LOWELL (1855–1916)

EMINENT AMERICAN ASTRONOMER, WHO MATHEMATICALLY PROVED YEARS AGO THE EXISTENCE OF THE NEWLY DISCOVERED PLANET PLUTO AND LIKEWISE SHOWED WHERE IT WAS TO BE FOUND IN THE SKY. HE FOUNDED, DIRECTED AND ENDOWED THE LOWELL OBSERVATORY, FLAGSTAFF, ARIZ.

Ever since celestial mechanics in the skillful hands of Leverrier and Adams led to the world-amazed discovery of Neptune, a belief has existed begotten of that success that still other planets lay beyond, only waiting to be found. Leverrier, himself, with the far-sight of genius, was firmly of this view, though unfortunately over-sanguine of the happy date of its demonstration. In consequence, since his time, many attempts have been made to indicate the position of one or more of these unknowns, attempts for the most part, of no scientific value because not founded on rigorous mathematical investigation. For so complicated is the problem that all elementary means of dealing with it lead only to error. The sole road to any hope of capture lies through the methodical approach of laborious analysis.

Not only are all summary processes worse than useless, engendering false ideas in their conclusions, even a supposed proximate analysis proves not to be approximate in its results. Thus the simplifying of the problem by the assumption of a circular orbit for the unknown, originally suggested by Tisserand and worked out in the present case with all due reserve by M. Gaillot, and more or less likewise by M. Lau, betrays intrinsic evidence of inadequacy. . . .

2. To any real solution, the problem must be attacked analytically with all the rigor possible. Before entering upon such an investigation, it is well to state the problem generally, showing the data upon which it rests, and the limitations to which it is necessarily subject. For lack of appreciation of these points has led to mistaken ideas of what is or is not possible.

3. The theory of a planet can not in the nature of things be exact; and this for three reasons:

(1) The observations on which it is founded are necessarily more or less in error;

(2) The theory, itself, may be more or less imperfect;

(3) An unknown body may be acting of which perforce no account has been taken. . . .

Then quoting from the conclusion:

In the next place, the solutions, themselves, tell us of alternatives between which they leave us in doubt to decide. If we go by residuals alone, we should choose those solutions which have their mean longitudes at the epoch in the neighborhood of 0°, since the residuals are there the smallest. But on the other hand, this would place the unknown now and for many decades back in a part of the sky which has been most assiduously scanned, while the solutions with ε' around 180° lead us to one nearly inaccessible to most observatories, and, therefore, preferable for planetary hiding. . . .

Owing to the inexactitude of our data, then, we can not regard our results with the complacency of completeness we should like. . . .

. . . Analytics thought to promise the precision of a rifle and finds it must rely upon the promiscuity of a shot gun after all, though the fault lies not more in the weapon than in the uncertain bases on which it rests. . . .

8. The investigation disclosed two possible solutions in each case, one with ε' around 0°, one with it around 180°; and that this duality of possible place would necessarily always be the case.

9. On the whole, the best solutions for the two gave:

Longitude	around 0°	around 180°
Long. Perihelion	= 22.°1	= 205.°0
Semi-major axis	= 43.0	= 44.7
m'	= 1.00	= 1.14
e'	= .202	= .195
Argument of Perihelion	= 203.°8	= 19.°6
hel. long. July 0, 1914	84.°0	262.°8

the unit of m' = $\frac{1}{50{,}000}$ the mass of the sun.

10. It indicates for the unknown a mass between Neptune's and the Earth's; a visibility of the 12–13 magnitude according to albedo; and a disk of more than 1″ in diameter.

11. From the analogy of the other members of the solar family, in which eccentricity and inclination are usually correlated, the inclination of its orbit to the plane of the ecliptic should be about 10°. This renders it more difficult to find.

12. Investigations on the perturbation in latitude yielded no trustworthy results. This is probably because the eccentricity of e' as well as the planet's other elements enter as data into the latitude observation equations.

13. The perturbative function is not discontinuous at the commensurability of period points, a fact hitherto in doubt.

14. That when an unknown is so far removed relatively from the planet it perturbs, precise prediction of its place does not seem to be possible. A general direction alone is predicable.

Thus Dr. Lowell found two regions of the ecliptic in diametrically opposite quarters of the sky, either of which might contain the trans-Neptunian planet. Yet it will be noted that his equations actually were a little more favorable to the position in which the

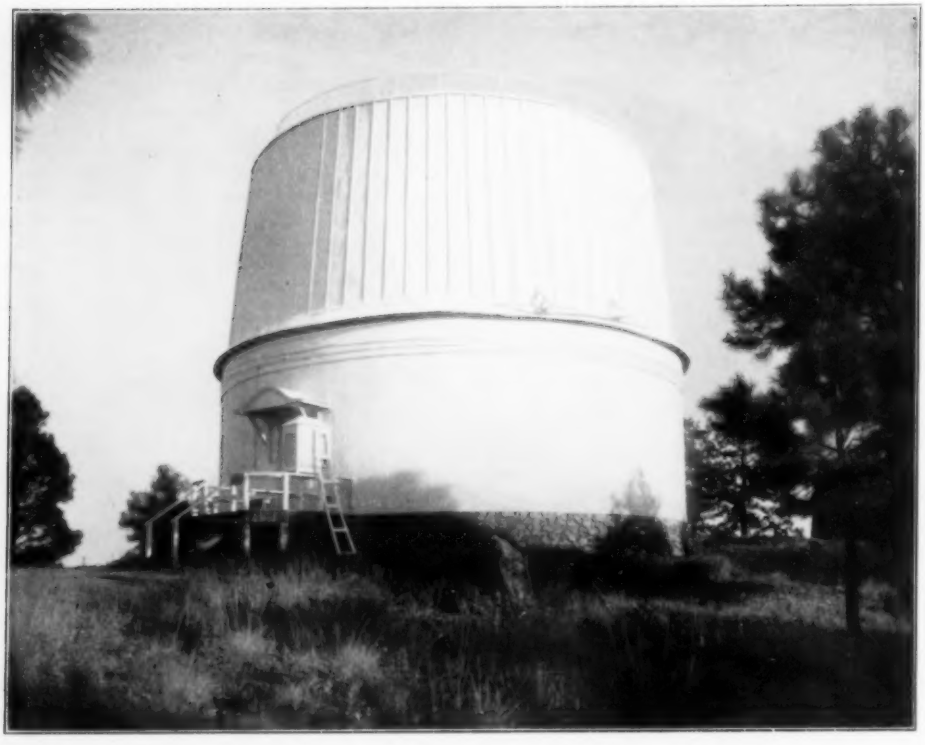


FIG. 1. THE DOME OF THE LARGE VISUAL TELESCOPE
THE FIRST UNIT OF THE LOWELL OBSERVATORY'S GROUP OF TELESCOPES.

planet was finally found. While this work was not completed and published until 1915, it was begun more than a decade earlier, and he had indeed found indications of the existence of the new planet as early as 1905. So encouraging were his theoretical findings, even then, that the preliminary steps on the search for the planet were taken under his direction that year. The interesting coincidence should here be pointed out that weak images of his Planet X were actually recorded on two plates made here the same year, 1915, that he made public his theoretical predictions, and were found last June by E. C. Slipher, aided by the known path of the planet.

It was early realized that to find the planet among the numerous stars only the methods of photography properly utilized could cope with the difficulties of the problem. It was clear that the method of procedure was to make two or more photographs of each small area of sky, at intervals of a few nights. These duplicate plates would then be carefully compared in such manner as to cause the predicted planet, when recorded on the plates, to reveal its presence by its shifting its position relative to the multitudes of stars, owing to its moving during the interval between the taking of the two plates.

After having some preliminary test exposures made, in 1905, by J. C. Duncan, Dr. Lowell procured from the John A. Brashear Company a special five-inch aperture photographic objective which, on a mounting assembled from available instrumental essentials by C. O. Lampland, gave good results.

Under Dr. Lowell's direction about

two hundred plates were secured with this 5-inch camera by E. C. Slipher in 1906 and 1907, and 50 odd by K. P. Williams, in the summer of 1907. This series covered the entire circuit of the sky centered along the invariable plane (the mean orbit plane of the planets), duplicate plates being made every 5°. The exposure times of the plates were of about three hours' duration in order to have the plates reach sufficiently faint stars—below the 16th magnitude (*i.e.*, ten magnitudes fainter than the unaided eye sees). The camera gave very sharp star images, but the size of field of sharp definition was small compared with those of the improved lenses of to-day.

Dr. Lowell examined these plates, but unfortunately he then had no suitable means for the purpose, and it was a very difficult task. The examination of such plates, even with the highly efficient means to-day, is much more time-consuming and difficult than the making of the plates.

The photograph in Fig. 5 shows a portion of one of the plates which often have more than 100,000 stars on a single plate. The degree of carefulness of the examination will be appreciated when it is stated that the plates must be examined so carefully that the image of the moving Planet X could only be singled out by its motion relative to the thousands of stationary stars on the plates.

Later the Hartmann comparator, intended for small spectrum plates, was enlarged and modified to make it serve for the sky plates, and was used by Lowell with some advantage over the hand magnifier methods he first employed. In his searching of these plates, his hopes were occasionally aroused by the behavior of an exceptional asteroid resembling temporarily that of a much more distant body.

After this considerable period of painstaking work with the Brashear camera, it became evident that an instrument of more power and larger field was needed. And also that an efficient comparator was required for the critical and expeditious examination of the plates. He then secured a Zeiss Blink comparator, which greatly facilitated the comparison and examination of the plates thereafter.[1]

Dr. Lowell next had an extensive series of plates made with the 42-inch reflector by C. O. Lampland and E. C. Slipher, aided by other members of the staff. With this powerful instrument, the requisite exposure time of the plates was comparatively short (less than ten minutes) and they still included sufficiently faint 17th magnitude stars. Thus the plates could be accumulated very rapidly. However, the smallness of the field of these plates with the large reflector meant that a few thousand of them were made and needed to cover even a moderate area of sky. Their examination, unfortunately quite a burdensome task, even with the efficient Blink instrument, was first carried on by Dr. Lowell, himself, and later by C. O. Lampland, who has published a considerable list of asteroids and variables found on these plates by himself and E. C. Slipher.

These years of searching, with the reflector, further emphasized the need of a wide-field, photographic telescope of considerable light-power. The ordering of such an instrument was planned, but Dr. Lowell was eager to keep pressing forward with the search, because of the encouraging results his theoretical investigations had yielded.

Fortunately, it was possible, through the kind interest of Dr. John A. Miller,

[1] Later, in 1919, those plates neighboring the place predicted by Dr. Lowell's Memoir were examined in the Blink comparator by E. C. Slipher, but we know now that the inclination of the new planet's path placed it just off the south edge of these plates.

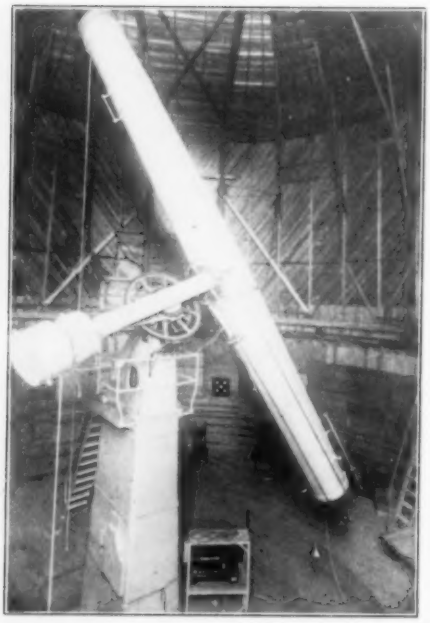


FIG. 2. THE LARGE LOWELL REFRACTING TELESCOPE

FAMOUS FOR STUDIES OF THE PLANETS AND FOR REVEALING THE ENORMOUS SPEEDS OF THE NEBULAE.

director of Sproul Observatory, to have the use for a time of that observatory's new photographic telescope. This instrument of 9 inches aperture by Brashear was used at Flagstaff from 1914 to 1916, and a large number of plates made with it, under Dr. Lowell's direction, chiefly by T. B. Gill and E. A. Edwards, supervised by C. O. Lampland. Only a partial examination of these plates was made by Lowell. Later Mr. Lampland surveyed the plates for asteroids and variables and listed 515 asteroids and 700 variable stars.

In the meantime the advent of the war had postponed the day when the new instrument could be had for the searching. This was no small disappointment to Dr. Lowell, coming at a time when he felt that theory had done all it could do, and the finishing of the task was clearly an observational one. And also he realized his Memoir would suggest the problem to other observatories then better provided instrumentally than was his, for the search.

But the result of his labors he was not to see come to full fruition, for, in 1916, death deprived the observatory of its founder and able leader, and further search for his Planet X had to be held in abeyance until a suitable instrument might be available.

In 1925, the glass disks for a 13-inch objective were offered for sale by the widow of the late Rev. Joel Metcalf. Though these disks were for an objective smaller than had been tentatively planned for the search, V. M. Slipher suggested to Mr. Guy Lowell, then trustee of the Lowell Observatory, that they would make an instrument which would serve at least greatly to advance the search for the planet, which Dr. Lowell's equations promised was waiting in the sky to be picked out from among the

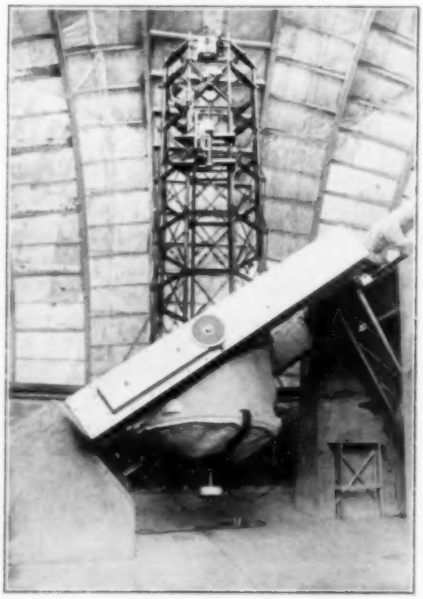


FIG. 3. THE 42-INCH REFLECTOR

WHICH HAS GIVEN EXCELLENT RESULTS IN THE PHOTOGRAPHY OF STARS, NEBULAE AND PLANETS, AND IN RADIOMETRIC WORK ON THE PLANETS.

stars. Mr. Guy Lowell, becoming deeply interested in the 13-inch glass disks and the prospect they offered for the much-needed instrument, personally purchased the glass, and went about planning to convert the rough-ground disks into a finished lens. Then, just as he was finding opportunity to touch more intimately the scientific problems of the observatory, he was overtaken by death, early in 1927.

Shortly thereafter the necessary money to complete the instrument and its mounting was generously provided by Dr. Percival Lowell's brother, President A. Lawrence Lowell, of Harvard. The making of the large objective was entrusted to C. A. R. Lundin, who, in due time, turned over to the observatory an excellent piece of optical work.

The objective was received in Flagstaff early in 1929, and was soon placed in its mounting. This mounting had meanwhile been under construction in the observatory shop in the able hands of Mr. Stanley Sykes, the observatory instrument-maker. The performance of the lens exceeded our expectations and we have been led to regard it as possibly the best search-instrument in the world to-day.

This instrument and its dome are fully equipped with electric conveniences, and it is much the most satisfactory to operate of any of the observatory's telescopes. It has a seven-inch aperture guide telescope, provided with a very sturdy diagonal prismatic eyepiece which makes for efficiency and comfort in observing.

The electric switches for operating the dome and the slow motion of the driving clock are conveniently placed for the observer at the guiding eyepiece. The setting circles are large, and arranged to make the accurate pointing of the instrument easy and quick. The driving clock is large and of excellent performance, and, as the worm wheel is exceptionally large and of highest quality, accurate guiding of the instrument is easy to attain.

The objective is of the Cooke three element "Astro" type, and has a focal length of 66.5 inches. It covers an unusually large plate—14 x 17 inches. As the definition is good over nearly the full width of the plate, about 150 square degrees of sky are well recorded on each plate. With an hour's exposure—the time commonly given—the plates record from about 50,000 to 500,000, or even more, stars, depending upon whether the region of the sky photographed is one with few or many stars.

On the tube of the main telescope is mounted a smaller camera for check purposes. This is a valuable adjunct, for occasionally on the plates of the main instrument will appear a questionable image, and the observer quickly decides its nature by looking it up on the plate of the check camera. This camera of 5-inches aperture and excellent quality is kindly loaned by Professor W. A. Cogshall, of Kirkwood Observatory, Indiana University. An 8-inch Ross type objective is now under construction to take the place of the lens on loan.

As soon as the large lens was placed in its mounting the preliminary adjustments and tests of the instrument were rushed to completion. And then promptly we began the first plates of the Planet X search series in order to get plates that season of Dr. Lowell's predicted favorable region in Gemini, then dropping rapidly into the evening sky. While the director was making the adjustments and tests of the new instrument, he instructed Mr. Tombaugh —who had recently come to the observatory—in the operation of the instrument, and also in the methods of photography, until he could carry through all the operations alone.

Our previous experience in such work

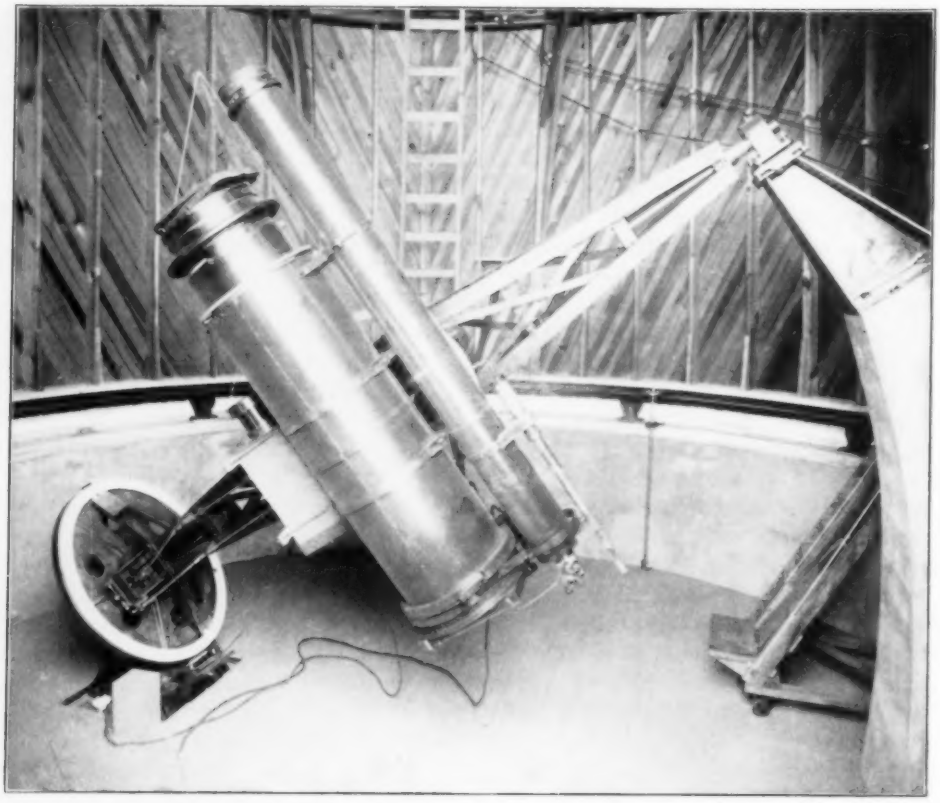


FIG. 4. THE NEW 13-INCH PHOTOGRAPHIC TELESCOPE
FAMOUS FOR HAVING BROUGHT TO LIGHT THE NEW PLANET.

impressed upon us the vital need with this new instrument of bringing each plate into exact focus in the telescope. To accomplish this we designed a convenient testing table, enabling the observer to bring the sensitive surface of every plate quickly into precisely the proper focal position, thus eliminating the all too frequent disastrous curvature faults of such large plates (14 x 17 inches). We designed also special plate holders supplied with special bearings for the plates over which thumb screws spring the plates into closest possible adjustment to the focal surface of the large lens. This insures that the focal qualities of all plates will be the same—a matter of the highest importance in the careful comparison of the plates.

It also was necessary to make tests of different photographic plates in order to take advantage of the most suitable available brand for this special work. For ease and accuracy in the examination, it is vital that the plates be exactly matched in the character of their photographic images, a result secured only by following a perfectly systematized procedure of photography as well as very precise instrumental adjustments.

Thus, in March, 1929, the search for the trans-Neptunian planet could at last be resumed, and with a conveniently operated and highly efficient instrument, well equipped with auxiliary apparatus, and with better perfected means and methods than were ever available before. The prospects were

promising, for it seemed such an object could not now long escape being detected.

Care was exercised in the choice of guide stars to cover effectively the desired region of the sky when Mr. Tombaugh began carefully to follow out the systematized search program. The work went on for nearly a year, with nothing more than the expected things coming up—numerous asteroids and variable stars—at least nothing very exciting.

Then, on February 18, 1930, when comparing by the Blink method two plates of the region about Delta Geminorum made January 23 and January 29, 1930, he came upon an object that had shifted among the stars, between the two dates, by an amount that on the face of it indicated the body was very distant, and perhaps the object long sought for. Fortunately, a third plate of the region was available, and it, too, showed the object. The reality of these images on the three plates could not be questioned as being the record of a distant, slow-moving, solar system body. But of course they were not in themselves sufficient to decide its nature, and it was necessary to go about securing additional observations and information from every possible view-point in order to decide the important matter.

The first question was, would the next plate show it in its expected place among the stars as estimated from the January positions. It did, and so did the next and the next plates. In short, the object continued to meet expectations. Our early fears were that it would speed up, and turn out to be only an exceptional asteroidal or cometary body.

As soon as possible, we pointed the large refractor upon it with one question uppermost in our minds—will it show a disk? It did not; that was disappointing. But we continued to scrutinize it carefully each night, and to compare it with neighboring stars to judge of its color, of the constancy of its light and to see if, under exceptionally favorable visibility, it might show some indication of a disk. Under the most careful scrutiny, it showed no sign of any cometary features. Mr. Lampland then photographed it with the large reflector to see what such plates might show, and, in particular, to follow its path and to get accurate positions for finding its orbit. The observations continued to find it night after night in its expected place.

Neither the eye observations at the visual telescope nor those with the photographic reflector indicated the slightest variation in its light. It was seen to be brighter visually, compared with some of the near stars of about its brightness, than it was on the photographs, indicating that it was not blue

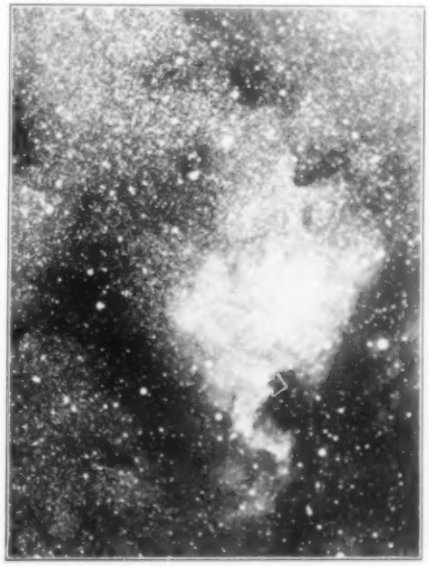


FIG. 5. SMALL SECTION OF A PLATE OF CYGNUS REGION OF SKY

MADE WITH 13-INCH TELESCOPE. IT SHOWS HOW THICK THE STARS ARE IN SOME REGIONS AND THIN IN OTHERS. THE PICTURE SHOWS THE FAMOUS AMERICA NEBULA.

FIG. 6. A SECTION OF ONE OF THE DISCOVERY PLATES

THAT OF JANUARY 23, 1930. THE ARROWS NEAR THE CENTER ARE POINTING TO THE LITTLE IMAGE OF PLUTO.

but yellow. The object is faint for the spectrograph and Mr. Lampland kindly made with the reflector a special pair of plates of it, one with blue light, the other with yellow light; and also a similar pair of the planet Neptune and its nearby stars. These plates agreed with what the eye had seen in the telescope, and indicated the stranger was yellowish, not bluish like Neptune. This color result implied an albedo (surface reflectivity)—like those of the inner planets—and also probably a high density. This was a bit surprising since its neighbors, Neptune and Uranus, are both of bluish color, of high albedo and of low density. Dr. Lowell's estimate of the magnitude was too high, doubtless in part because he naturally was influenced by the very high albedos of Uranus and Neptune.

Meanwhile, it was possible for us to follow it every night and to lay out its expected path empirically, and we were encouraged each succeeding night to find the object just where we estimated it would be. It was keeping a steady course. It was possible after a while to predict within a day or two when it would reach the end of its westward swing (its stationary point) in the sky, and would start moving eastward, reversing its drift among the stars. Its apparent motion was, of course, largely due to our own shifting view-point, caused by the Earth's daily swinging through about one degree of its orbit around the sun. The photograph in Fig. 9 shows its apparent path among the stars as charted by Dr. Lampland from the search plates and those he made at the reflector.

The observed amount of its drift from day to day afforded a measure of its distance from us. Thus, after a few weeks, it showed that its distance was definitely much greater than Neptune's and between 40 and 43 times the distance the earth is from the sun. Its drift rate was the distinguishing test for distance, and from the discovery plates

FIG. 7. MR. C. W. TOMBAUGH

THE CAREFUL-WORKING AND KEEN-EYED YOUNG MAN WHO WAS FIRST TO FIND THE RECORD OF PLUTO ON THE PHOTOGRAPHIC PLATES.

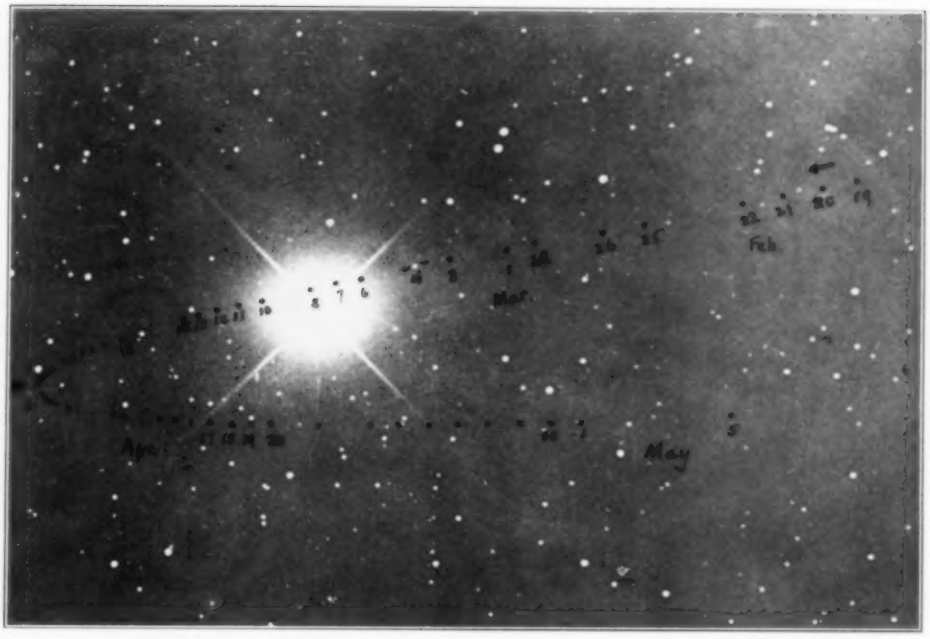


FIG. 8. PLUTO

APPARENT PATH OF THE PLANET AMONG THE STARS, FEBRUARY 19 TO MAY 10. DATE OF PHOTOGRAPH MARCH 4, 1930. THE POSITIONS, EXCEPT THE FIRST FOUR, ARE FROM 42-INCH REFLECTOR PHOTOGRAPHS BY C. O. LAMPLAND. THE BRIGHT STAR IS δ GEMINORUM. SCALE $1^{mm} = 7''.3$ (APPROX.).

on continued to show the object was trans-Neptunian.

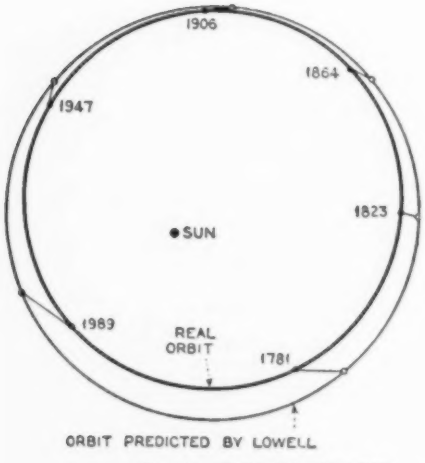
Finally, on the night of March 12, a message was telegraphed to Mr. Putnam, the observatory trustee, to be forwarded to Harvard Observatory for distribution, the next day to observatories and astronomers, which read as follows:

> Systematic search begun years ago supplementing Lowell's investigations for Trans-Neptunian Planet has revealed object which since seven weeks has in rate of motion and path consistently conformed to Trans-Neptunian body at approximate distance he assigned. Fifteenth magnitude. Position March twelve days three hours GMT was seven seconds of time west from Delta Geminorum, agreeing with Lowell's predicted longitude.

The announcement of the finding of Lowell's planet was delayed a few days in order that it might be made on the anniversary of his birth—March 13. It was also made public on that morning at the Arizona Teachers College in the presentation of a scholarship prize given each year in Dr. Percival Lowell's memory by his widow, Mrs. Constance S. Lowell.

It is a coincidence worthy of remark that March 13 is also the anniversary of Sir William Herschel's discovery of the planet Uranus.

In passing, we can only remark upon the tremendous, instant, and persistent demand from the public press for information. We did not feel at that time that we had much ready to give out, and were, besides, too much occupied in following the urgent phases of the work to do more than give a few brief comments. The number of telegrams, cablegrams and letters received at the obser-



—*Courtesy Scientific American*

FIG. 9. THE ACTUAL AND THE PREDICTED ORBITS OF PLUTO

THE REAL POSITIONS OF THE PLANET AT INTERVALS FROM 1781 TO 1989, AND THE POSITIONS RESULTING FROM LOWELL'S CALCULATIONS.

vatory, as well as the large amount of space given the finding of the new planet by the newspapers and magazines, is clear proof of the wide-spread interest in astronomy to-day.

We felt it highly desirable to determine as soon as possible a preliminary orbit for the object, although we fully realized such orbit would be very imperfect in most respects because all the observations then available covered only an exceedingly short section—about 1/1500 part—of the planet's swing around the sun. It seemed that a start should be made, even if some of the orbital elements—its shape and size—could not really be determined, because even an approximate orbit would help show its approximate path for a time in the past and hence assist in indicating where to look for the planet on old plates.[2] For this work, we fortunately had the collaboration of Dr. J. A. Miller, director of the Sproul Observatory, whose experience in orbit work was very valuable in this difficult case. The orbit derived served its purpose, although its eccentricity and period were very much in error, as we feared they would be.

A circular was then issued, giving the preliminary orbit and some further results of the observational work, and stating as a conclusion that this object

> appears to be a trans-Neptunian, non-cometary, non-asteroidal body that fits substantially Lowell's predicated longitude, inclination and distance for his Planet X.

It was also then suggested that the planet be named Pluto, and carry the symbol PL. Many people have asked why we chose the name Pluto. We considered carefully the numerous suggestions offered by many serious minded people. Minerva received a plurality,

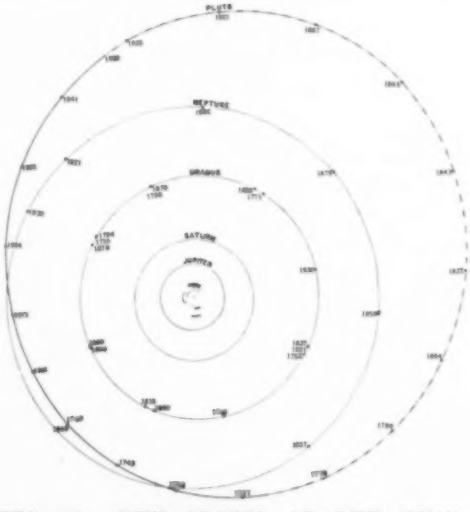


FIG. 10. THE ORBITS OF THE NINE PLANETS TO SCALE AS THEY REVOLVE ABOUT THE SUN

THE POSITIONS OF URANUS, NEPTUNE AND PLUTO FOR THE VARIOUS YEARS ARE AS INDICATED. THE ORBIT OF PLUTO IS CONSIDERABLY INCLINED TO THAT OF NEPTUNE AND HENCE THESE TWO ORBITS DO NOT INTERSECT. DIAGRAM BY C. O. LAMPLAND.

[2] It was later found on our 1929 plates, the tenth plate with the new instrument having recorded it.

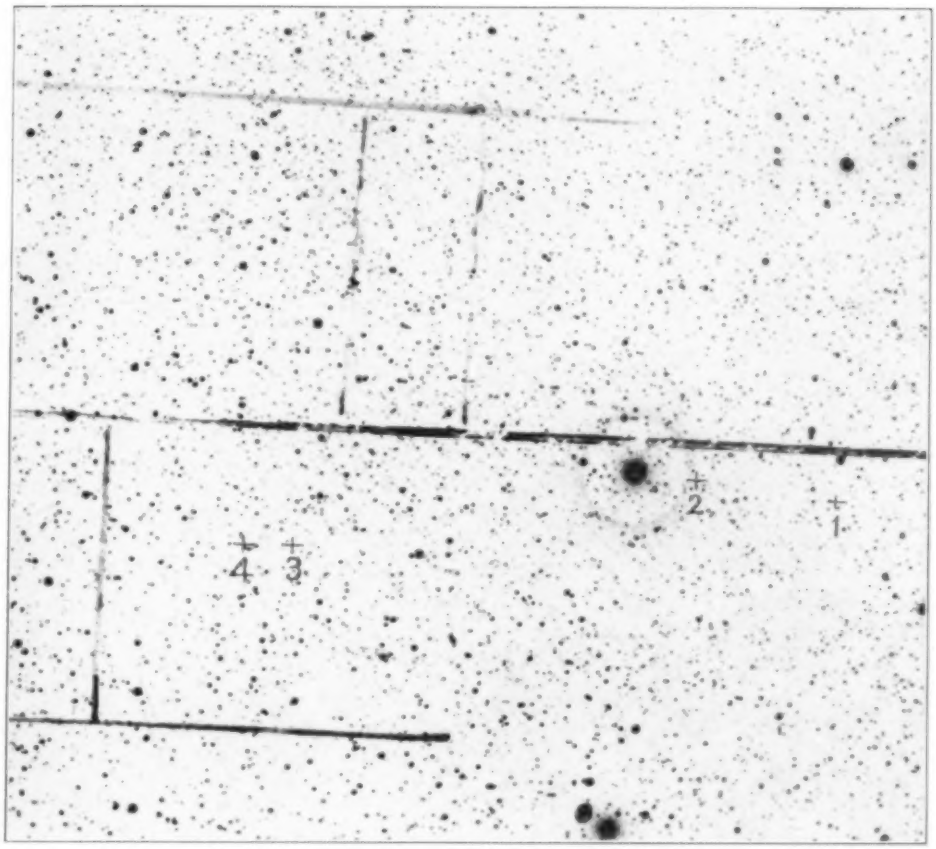


FIG. 11. STAR FIELD AROUND δ GEMINORUM

FROM OLD 5-INCH SEARCH PLATE MADE DECEMBER 18, 1906, BY E. C. SLIPHER. OF SPECIAL INTEREST IS THIS 24-YEAR-OLD PLATE BECAUSE IT SHOWS THE RECTANGULAR EXAMINATION MARKS PLACED THEREON BY DR. LOWELL, ROUND ABOUT WHERE THE PLANET LATER APPEARED ON THE DISCOVERY PLATES. DOTS 1 AND 2, AND 3, AND 4, MARK WHERE PLUTO WAS PHOTOGRAPHED IN 1930 AND 1929, RESPECTIVELY. NO. 1 IS THE DISCOVERY PLACE.

nearly half the letters suggesting this name. We, too, would have liked to use it if it had not been preempted long since by one of the earlier asteroids.

A great many other names were suggested, but the two most popular ones were Cronus and Pluto. Mythologically, there were very good reasons for both. But Pluto is much better known, and his two brothers, Jupiter and Neptune, are already in the heavens. When these three brothers drew lots for the partition of the world, Pluto chose the outer regions. What then could be more appropriate than his now being in these outer regions, and being in the heavens with his two brothers?

The symbols of all the existing planets, except that of Neptune, are so conventionalized and similar that we felt that the proper symbol for Pluto would be the letters "PL" in the form of a monogram which would be easy to write, and to the layman would bring Pluto to mind. The fact that these were Percival Lowell's initials added weight to the thought.

A few astronomers were inclined to

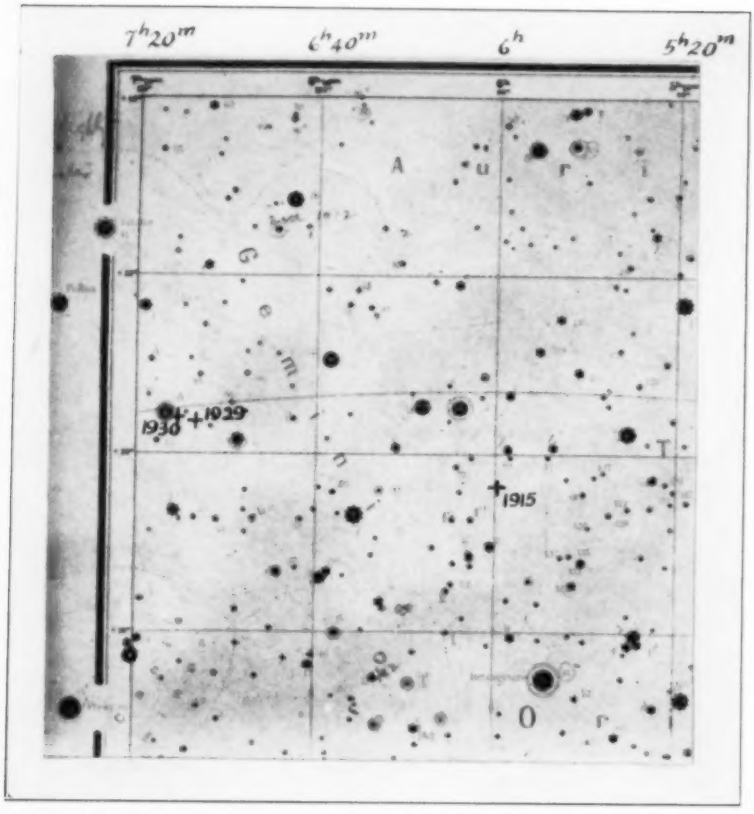


FIG. 12. PHOTOGRAPH FROM A STAR CHART OF THE CONSTELLATIONS GEMINI AND TAURUS

WHICH IS MARKED TO INDICATE ROUGHLY THE POSITIONS PLUTO OCCUPIED IN THE YEARS 1915, 1929, 1930.

question the nature of the object because of the high eccentricity of our first orbit, but this was only temporary. Not long afterwards better orbits were possible because they could be based on much more favorably timed observations and several such orbits were soon forthcoming. These left little doubt as to the nature of the object.

It will now be of interest to see how the recent orbits, determined from the more extended path of the planet and quite reliable, check with what Dr. Lowell had predicted. Dr. A. C. D. Crommelin, of England, whose life work has been largely in the orbit field, wrote on May 20:

I send circular with the orbit that I deduced for the new planet, assuming that it was photographed at Uccle in 1927. It is in good accord with Lowell's forecast:

	He (Lowell) gave	My (Crommelin) value
Long. of Perih.	205°	216
Perih. passage	1991	1884.9
Period	282 yrs.	265
Eccentricity	.202	.287
Inclination	10°	17

It is *very* difficult to think that all these points are pure flukes!

. . . . . .

It was not till my orbit was in print that I made the comparison with Lowell's prediction, so that there was no *cooking* in arriving at the agreements.

In an article entitled "More About Pluto," Dr. Henry Norris Russell, in

Scientific American, December, 1930, wrote:

> In the second place, the orbit, now that we know it, is found to be so similar to that which Lowell predicted from his calculations 15 years ago that it is quite incredible that the agreement can be due to accident. Setting prediction and fact side by side, we have the following table of characteristics:

	Predicted	Actual
Period	282 yrs.	249.17
Eccentricity	0.202	0.254
Long. of Perihelion	205°	212°30′
Perihelion Passage	1991.2	1989.16
Inclination	about 10°	17°9′
Longitude of node	not predicted	109°22′

Lowell saw in advance that the perturbations of the latitudes of Uranus and Neptune (from which alone the position of the orbit plane of the unknown planet could be calculated) were too small to give a reliable result, and contented himself with the prophecy that the inclination, like the eccentricity, would be considerable. For the other four independent elements of the orbit, which are those which Lowell actually undertook to determine by his calculations, the agreement is good in all cases, the greatest discrepancy being in the period, which is notoriously difficult to determine by computations of this sort. In view of Lowell's explicit statement that, since the perturbations were small, the resulting elements of the orbit could at best be rather rough approximations, the actual accordance is all that could be demanded by a severe critic.

Even so, the table does not tell the whole story. The diagram Plate on page [Fig. 9, p. 16] shows the actual and the predicted orbits, the real positions of the planet at intervals from 1781 to 1989, and the positions resulting from Lowell's calculations.

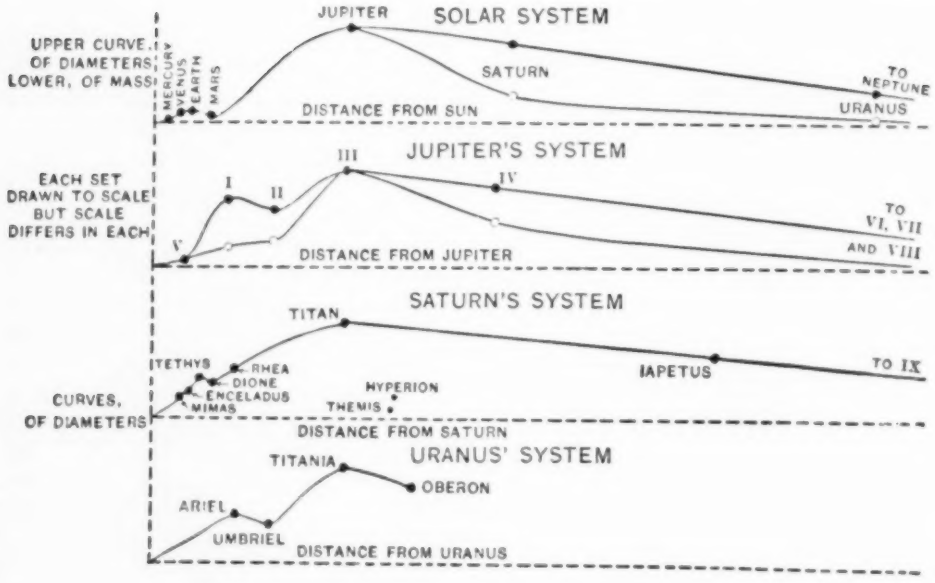
In brief, Pluto's credentials as a member of the Sun's family of planets are of high standing and have been fully approved, and he stands the ninth in discovery and in order of distance from the Sun.

It was early realized that the faintness of Pluto would, in itself, make the detection of a disk much more difficult than if it were brighter. Tests of a specially designed target of various illuminated graduated apertures set up about a mile away, and observed through the large telescope, counterparting the observations of the new planet and with the same telescope, confirmed indications of theory. These observations, carried out mainly by E. C. Slipher, experienced in the observation of small satellite disks, and checked by one of us, indicated that Pluto could have a disk of nearly 5/10 of a second of arc and not be detected by our best observations. However with most favorable—much brighter—lighting of such an object about half this size of disk would be detectable. Now our Earth, if seen at the distance of Pluto, would have a disk of only 43/100 of a second of arc, and under faint lighting would probably not be seen to show a disk. Certainly no disk could be seen if its albedo were as low as that of Mercury or the moon. Or, in other words, these experiments indicate that Pluto owing to its faintness could have a diameter as large as or a little larger than the earth and its disk not be recognizable under our best observing conditions.

Hence it is possible that Pluto may be at the most about 10,000 miles in diameter, of a very low reflectivity comparable with that of Mercury, and have a density possibly equal to that of the Earth. Such a planetary body would fit the observations to date without serious conflict. If, sometime, a satellite should be discovered for Pluto, we could readily get his mass accurately.[3]

The color of Pluto indicates for him a very different atmosphere from that which envelops Neptune; and, for all we can tell, Pluto, like Mercury, may be destitute of atmosphere. Of all the planets, these two obviously have the greatest extremes in the intensity of

[3] Since this was written, Nicholson and Mayall have published their work on the probable mass of Pluto, indicating a mass approaching to the Earth's.



MASSES OF PLANETS AND SATELLITES.

—*Courtesy Macmillan Co.*

FIG. 13. DIAGRAM

SHOWING THE SIZE AND DISTANCE RESEMBLANCES BETWEEN THE SUN AND ITS PLANETS AND THE GIANT PLANETS AND THEIR OWN FAMILIES OF SATELLITES.

sunlight they receive. Because of its great distance, the sunlight that the new planet receives has only about 1/1700 the intensity of that which the earth enjoys. Hence this very remote planet is so little warmed by the Sun that it has, no doubt, a very low temperature. To one on Pluto our Sun would not show any disk but only a bright star point, to the unaided eye.

Owing to the considerable eccentricity of his orbit the light and heat Pluto receives from the sun will differ greatly depending on where he is in his orbit. This means that his brightness also will vary considerably for us. He is now growing slowly brighter because he is nearing the sun and us. He will continue to brighten until the year 1989, after which time he will begin to grow fainter for the following 125 years during which time he will be receding from the sun as he swings out into the most distant portion of his great orbit.

At present, we know nothing of the length of Pluto's day, and our only hope of learning anything of his diurnal rotation is by his showing a measurable periodic variation in light—a not too remote prospect. Pluto's year, as was noted a bit ago, is about 250 of our years, and is already fairly accurately determined. Hence he goes slowly around the Sun, trailing at a greater distance his more speedy brothers. It is interesting to note that his year is almost exactly 3 times as long as that of Uranus and quite closely $1\frac{1}{2}$ times that of Neptune.

It will now be of interest to consider for a moment the arrangement of the members of our solar system.

Fig. 13 is from Dr. Lowell's book, "The Evolution of Worlds." It is interesting here because the addition of the new ninth planet to the solar system makes still more striking the resemblance between the Sun with his family

of planets, and that of Jupiter and his family of satellites (seen in the two upper curves). In drawing attention to this matter Lowell concludes: "Method here is unmistakable."

The high inclination of Pluto's orbit, too, fits in with this scheme as the inclination of some of the outer satellites of these families is extreme.

Thus the finding of Pluto is impressive, not merely because it adds another planet, and greatly expands the known domain of the Sun, but also because it hints that, out in this new extension of the Sun's domain, planetary affairs may differ markedly from what we might have supposed, influenced by our acquaintance with the previously known planets.

The fruitful issue of his courageous exploration of the solar system beyond Neptune is a fitting and lasting tribute to the genius of Dr. Percival Lowell, for two decades the outstanding worker in planetary investigations. He pursued his research problems with rare insight and an enthusiasm that would not yield to unfavorable criticism. And he provided for his observatory's continuance after he would be gone. It is especially lamentable that he could not live to see the confirmation that has come to many of his conclusions and now crowned by the finding of his trans-Neptunian planet. This is at the same time no small reward for the long years of persevering work of the observatory staff always doing their utmost to bring to successful completion the observatory program inspired and sustained by his earlier leadership.

THE NATURE OF METALS IN RELATION TO THEIR PROPERTIES

By EARLE E. SCHUMACHER

METALLURGIST, BELL TELEPHONE LABORATORIES

Introduction

The methods of extracting metals from their ores and fabricating them constituted the art of metallurgy in the older sense, an art whose development has closely paralleled the rise of civilization. The modern science of metallurgy, on the other hand, concerns itself to a large extent with the explanation as to why metals behave as they do and in particular why the methods employed in the art produce the effects they do. This science, as distinct from the art, is of comparatively recent origin. It is, indeed, only since the development of the tools used in modern research, notably the microscope and x-ray, that important steps have been made toward the analysis of metallic structure. Rapid progress has been made in the last twenty years and to-day there is available a vast fund of information in regard to the nature of metals in relation to their properties.

Two of the most important properties of a metal are its hardness and strength. These properties are closely related and in general the magnitude of one indicates the magnitude of the other. The development of the relationship between the nature of a metal and the hardness and strength constitutes one of the most interesting chapters in the science of modern metallurgy.

The Nature of Metals and the Meaning of Hardness

Metals, in general, are solids at room temperature. Most solids are composed of a number of irregularly shaped crystals pressing closely against each other. This is schematically represented in Fig. 1, which shows a cross-section through such an aggregate. X-ray studies have shown that the crystal itself is composed of minute building blocks or atoms, which are arranged in a regular geometrical pattern called the space lattice. The dimensions and shape of this lattice are different for the different metals. Most common metals, however, have a face-centered cubic lattice, a unit of which is shown in Fig. 2a. The position of the atoms in the lattice determines certain planes which extend throughout each individual crystal. Two sets of these planes are illustrated in Figs. 2b and 2c. In 2b the planes are shown parallel to a cube face; in 2c the planes are drawn through the cube edges. It is fairly obvious that sliding may take place easily between these planes, since there are no atoms to interfere with the relative motion of the two sections. Actually, sliding or slip, as it is generally termed, occurs more readily along one plane than another due to the difference in spacing between planes and the concentration of the atoms on adjacent planes.

From this brief description of the nature of the lattice it is apparent that the hardness or the strength of a single crystal of a metal depends upon the resistance to an applied force encountered when the various planes of atoms slide over one another. This sliding of the atomic planes constitutes the mechanism involved in permanent or plastic deformation. Sections of the crystal slide over one another but each section moves intact. This is illustrated in Fig. 3 which shows the slip bands developed on a polished surface of lead by plastic deformation. The projection of the sections which have slipped above the polished surface of the specimen has given

rise to the series of parallel lines visible in each crystal face. The same action is illustrated in Fig. 3a which is a schematic representation of the progress of slip when a single crystal is deformed in tension.

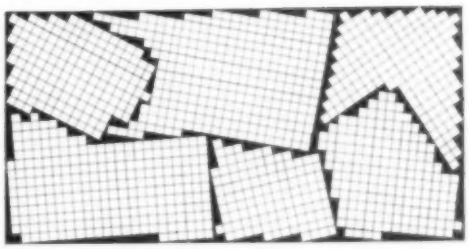


FIG. 1. SCHEMATIC REPRESENTATION OF METALLIC GRAINS.

The Causes of Hardness

The term hardness is commonly used in a rather vague and general sense, but the principle properly associated with the term, at least when referred to metals, is the ability to resist plastic deformation. Since deformation is the result of the sliding of crystal sections on slip planes, any alteration in the metal aggregate which interferes with slip will cause an increase in hardness. Some metallurgical processes which produce useful hardness in metallic materials are: (1) alloying of two metals to form a solid solution, (2) cold work, and (3) heat treatment.

The alloying of two metals to form a solid solution results in a crystal lattice containing both kinds of atoms. The lattice of the solvent persists, but the differences in potential fields surrounding the two types of atoms have very important effects. There is probably not only a general tightening of atomic bonds but also some distortion of the slip planes caused by displacement of atoms from their regular positions. Either of these effects may be sufficiently great to increase resistance to slip. The conception of lattice distortion is illustrated in Fig. 4. The figure in the upper left illustrates schematically a cross-section through a metal consisting of one

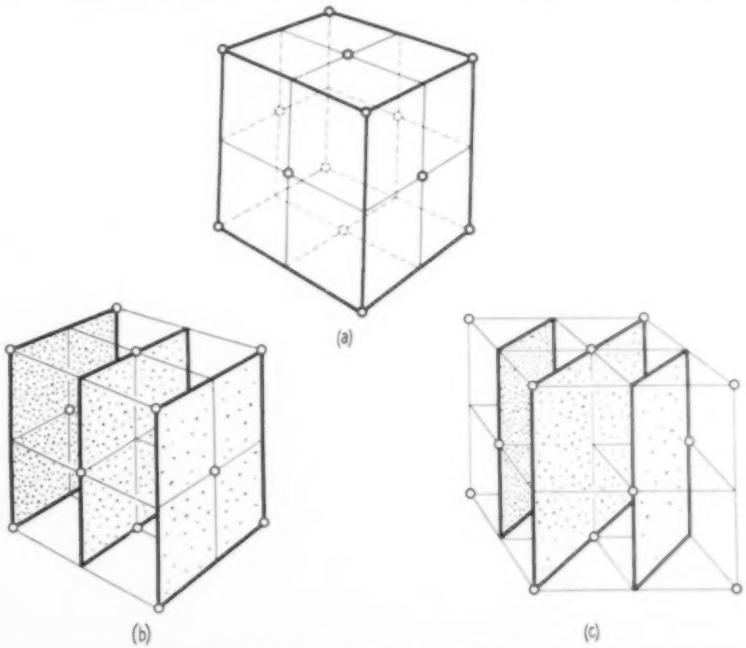


FIG. 2. TWO SYSTEMS OF PARALLEL PLANES THROUGH A CUBICAL ARRANGEMENT OF ATOMS.

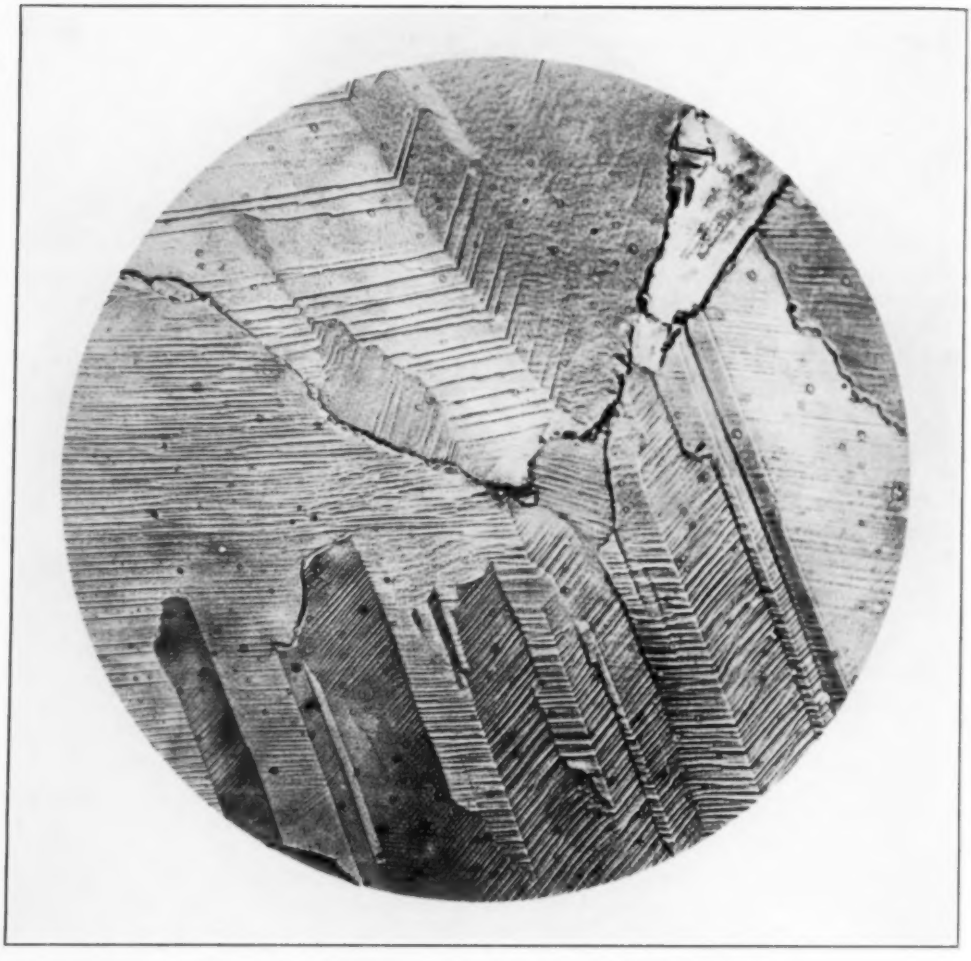


FIG. 3. PHOTOMICROGRAPH OF STRAINED LEAD
SHOWING SLIP BANDS AND TWINS. ORIGINAL MAGNIFICATION 150 ×.

kind of atom. The figure in the upper right shows the local distortion caused by a single foreign atom in solid solution.

Cold work, where hardness is caused by bending, rolling, hammering, drawing, or otherwise deforming the metal when cold, is one of the most important methods of hardening and strengthening metals. Some familiar materials which are hardened in this way are hard-drawn copper, spring brass and bronze, and cold-rolled steel. The mechanism of hardening by cold work seems very complex. Worked metals show a general breaking up of large crystals into small fragments. There is also considerable elongation of the individual crystals in the direction of working. X-ray studies reveal that the planes of atoms undergo a change of orientation during working and that the lattice is severely strained. This indicates that the hardening due to cold work may be caused by at least two factors; lattice distortion, such as occurs in solid solution hardening, and disregistry of slip planes from fragment to fragment.

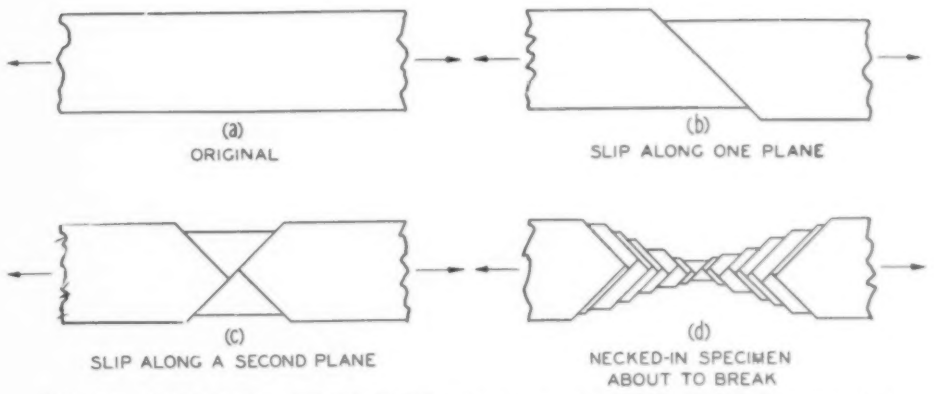


FIG. 3A. SCHEMATIC REPRESENTATION OF PLASTIC DEFORMATION (BY TENSION) OF A METAL BAR COMPOSED OF A SINGLE CRYSTAL.

The third type of hardening, hardening by heat treatment, depends upon the presence in the metal of two or more phases (homogeneous parts), the relative quantities of which depend upon the temperature of the metal. To produce an increase in hardness in the metal, the heat treatment and subsequent operations must increase the amount of that phase which stiffens the lattice. The stiffening is probably caused by precipitated particles of the second phase keying slip planes. This subject of keying is discussed in more detail later. The nature of the heat treatment differs with

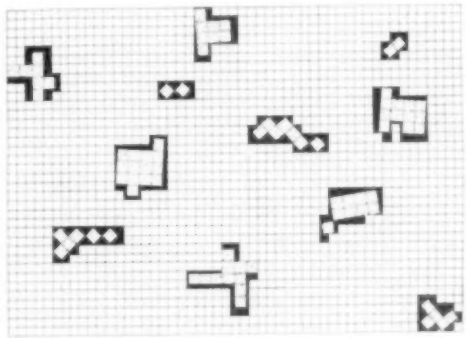
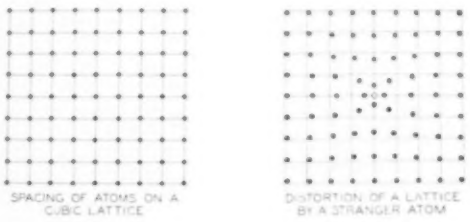


FIG. 5. SCHEMATIC REPRESENTATION OF THE KEYING OF SLIP PLANES BY PRECIPITATED PARTICLES.



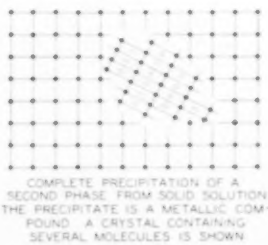

COMPLETE PRECIPITATION OF A SECOND PHASE FROM SOLID SOLUTION. THE PRECIPITATE IS A METALLIC COMPOUND. A CRYSTAL CONTAINING SEVERAL MOLECULES IS SHOWN

FIG. 4. LATTICE DISTORTION

different systems. In some cases a single quench from a high temperature suffices to produce an extremely hard material. Carbon steel is such an alloy. Another method of hardening certain alloys consists of a double heat treatment. In this treatment the alloy is heated at a high temperature and quenched. This treatment is followed by an aging at a lower temperature. Commercial alloys which are hardened by this method are duralumin, tempalloy, lead-calcium and lead-antimony. A study of this latter type of hardening has resulted in extremely interesting developments in connection with the nature of metals. Because of this, a brief historical account of the evolution of this method, together with

a fairly detailed discussion of one plausible age hardening theory seems in place.

Age Hardening of Metals

Age hardening was discovered in 1911 by Dr. Alfred Wilm while experimenting with aluminum alloys. It was not until 1919, however, that Dr. P. D. Merica and his associates discovered the fundamental condition necessary for this type of hardening to occur, which is that there must be present a constituent in the alloy whose solubility in the solid state decreases with decreasing temperature. When the alloy is held at a high temperature, this constituent dissolves. Upon cooling quickly, the constituent remains dissolved, but the solid solution is supersaturated. The alloy is now only a little harder than the original solvent. During subsequent aging at a lower temperature, the supersaturated solution breaks down, the excess solute precipitates in small particles evenly distributed, and the alloy hardens.

In 1921, an explanation of the hardening action was proposed by Jeffries and

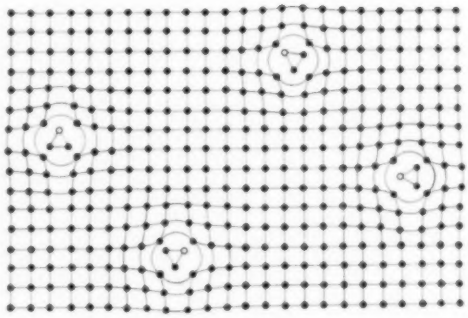


FIG. 6. LATTICE DISTORTION CAUSED BY PRECIPITATED PARTICLES.

Archer. They suggested that the precipitated particles act as keys locking adjacent planes of atoms together so as to interfere with relative motion or slip. This explanation has become widely known as the "Action as Keys" theory of the mechanism of age-hardening. Figs. 4 (bottom diagram) and 5 indicate how slip planes are keyed by precipitated particles.

Since the "Action as Keys" theory was first proposed, a number of modifications have been suggested. It has, for instance, been proposed that the precipi-

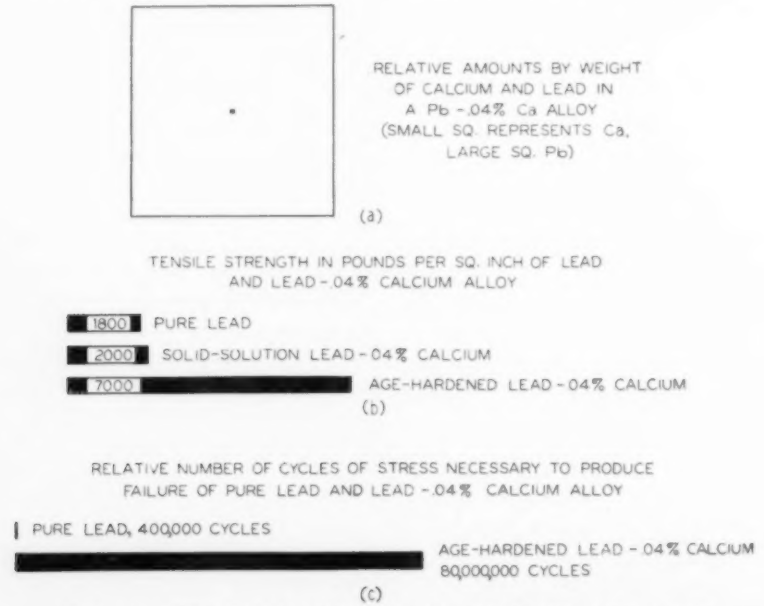

RELATIVE AMOUNTS BY WEIGHT OF CALCIUM AND LEAD IN A Pb - .04% Ca ALLOY (SMALL SQ. REPRESENTS Ca, LARGE SQ. Pb)
(a)
TENSILE STRENGTH IN POUNDS PER SQ. INCH OF LEAD AND LEAD - .04% CALCIUM ALLOY
1800 PURE LEAD
2000 SOLID-SOLUTION LEAD - 04% CALCIUM
7000 AGE-HARDENED LEAD - 04% CALCIUM
(b)
RELATIVE NUMBER OF CYCLES OF STRESS NECESSARY TO PRODUCE FAILURE OF PURE LEAD AND LEAD - .04% CALCIUM ALLOY
PURE LEAD, 400,000 CYCLES
AGE-HARDENED LEAD - 04% CALCIUM 80,000,000 CYCLES
(c)

FIG. 7. RELATIVE AMOUNTS OF CALCIUM AND LEAD

tation of the solute introduces strain in the lattice and so distorts the atom planes, thus retarding slip. This mechanism is shown schematically in Fig. 6. It is evident that this theory does not differ from the solid solution theory of hardening except that the distorting effects may be greater and consequently higher hardness values may be obtained. According to these theories it seems entirely justifiable to say that the mechanism of age-hardening depends upon slip interference and it is quite probable that both mechanical keying and distortion keying contribute toward the hardening attained. Under certain conditions and in certain systems mechanical obstruction may predominate; under other conditions and in other systems distortion keying may be the important factor. For instance, in the early stages of precipitation before agglomeration has had time to progress appreciably, it is probable that distortion hardening predominates. In the later stages, after the precipitated particles have agglomerated, mechanical obstruction is probably the major factor in producing hardness. A schematic representation of a precipitated phase that is causing practically no distortion of the solvent lattice is given in the bottom diagram of Fig. 4.

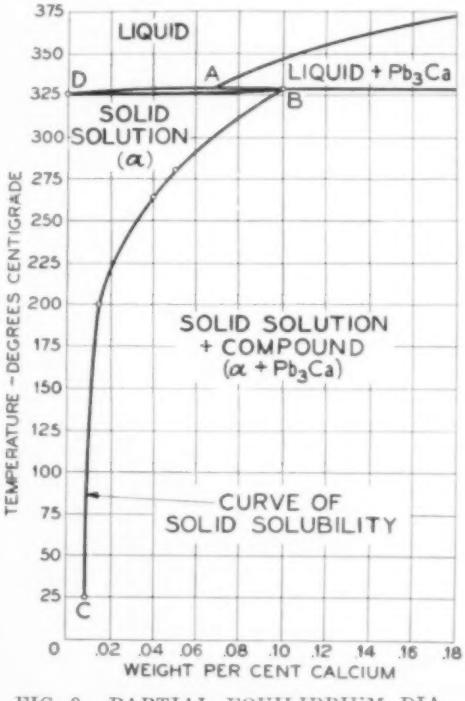


FIG. 9. PARTIAL EQUILIBRIUM DIAGRAM OF THE SYSTEM LEAD–CALCIUM.

FIG. 8. MACROGRAPH OF A PURE LEAD SHEATH WHICH FAILED IN SERVICE DUE TO INTERCRYSTALINE FRACTURES.

A Typical Age-Hardening Alloy

Of the many dispersion hardening systems which have been reported to date, the alloys of lead and calcium are interesting because of the exceedingly minute quantity of calcium which suffices to produce the age-hardening

phenomenon. Fig. 7a represents graphically the proportions of calcium in a lead – .04 per cent. calcium alloy. Fig. 7b shows the tensile strengths of pure lead, solid-solution lead – .04 per cent. calcium alloy, and age-hardened lead – .04 per cent. calcium alloy. From this figure, it is evident that solid-solution lead – .04 per cent. calcium is only slightly stronger than pure lead, whereas the age-hardened alloy has a tensile strength nearly four times that of pure lead. According to theory, finely dispersed particles of a lead-calcium compound, Pb_3Ca, precipitate from the solid-solution lead – .04 per cent. calcium alloy when the latter is aged at room temperature, and the great increase in tensile strength is brought about by these particles keying and/or distorting slip planes.

In Fig. 7c is shown the great increase in fatigue resistance (ability to withstand repeated cycles of stress without fracture) of the age-hardened lead-calcium alloy over that of pure lead. For some kinds of use, such for example as in the sheath of aerial telephone cable, which is exposed to repeated stresses and vibrations, it is expected that the high fatigue endurance of lead-calcium will prove to be valuable.

The aerial telephone cables in this country compose a very costly network of wires protected by many thousands of miles of lead alloy sheath. The stresses and vibrations to which these sheaths are exposed include not only those brought about during installation, but also, and probably more important, those occurring later due to expansion and contraction caused by daily and seasonal temperature changes, and vibrations caused by wind and by the movement of heavy vehicles and trains. On account of the bends which occur in cables at the points of support on the poles, thus localizing the strains, sheath failure is most likely to occur at these points. Since the insulation of the wires in these cables consists of coverings of dry paper, it is evidently important to avoid even small openings in the sheath which might admit moisture. Pure lead as a sheathing material for aerial telephone cable is unsatisfactory, as its service life, probably because of its relatively low

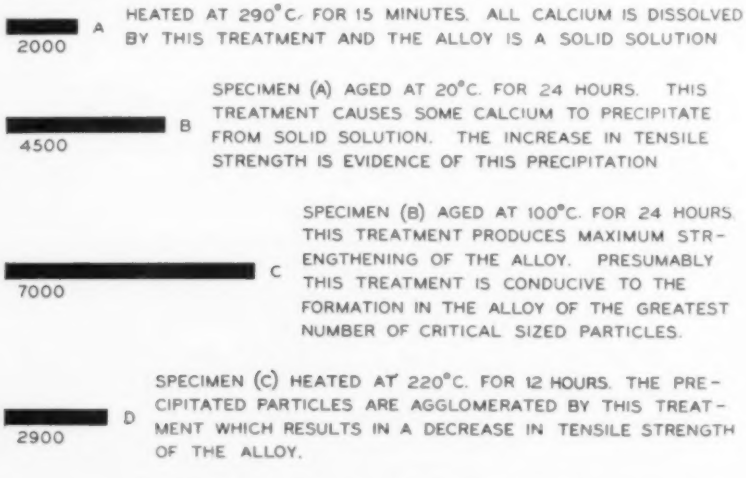

A
2000
HEATED AT 290°C. FOR 15 MINUTES. ALL CALCIUM IS DISSOLVED BY THIS TREATMENT AND THE ALLOY IS A SOLID SOLUTION
B
4500
SPECIMEN (A) AGED AT 20°C. FOR 24 HOURS. THIS TREATMENT CAUSES SOME CALCIUM TO PRECIPITATE FROM SOLID SOLUTION. THE INCREASE IN TENSILE STRENGTH IS EVIDENCE OF THIS PRECIPITATION
C
7000
SPECIMEN (B) AGED AT 100°C. FOR 24 HOURS. THIS TREATMENT PRODUCES MAXIMUM STRENGTHENING OF THE ALLOY. PRESUMABLY THIS TREATMENT IS CONDUCIVE TO THE FORMATION IN THE ALLOY OF THE GREATEST NUMBER OF CRITICAL SIZED PARTICLES.
D
2900
SPECIMEN (C) HEATED AT 220°C. FOR 12 HOURS. THE PRECIPITATED PARTICLES ARE AGGLOMERATED BY THIS TREATMENT WHICH RESULTS IN A DECREASE IN TENSILE STRENGTH OF THE ALLOY.
E
2000
SPECIMEN (D) HEATED AT 290°C. FOR 15 MINUTES. ALL PRECIPITATED COMPOUND IS DISSOLVED BY THIS TREATMENT ALLOY HAS PROPERTIES IDENTICAL WITH THOSE OF SPECIMEN A

FIG. 10. TENSILE STRENGTH IN POUNDS PER SQUARE INCH OF LEAD—.04 PER CENT. CALCIUM ALLOY IN DIFFERENT HEAT-TREATED CONDITIONS.

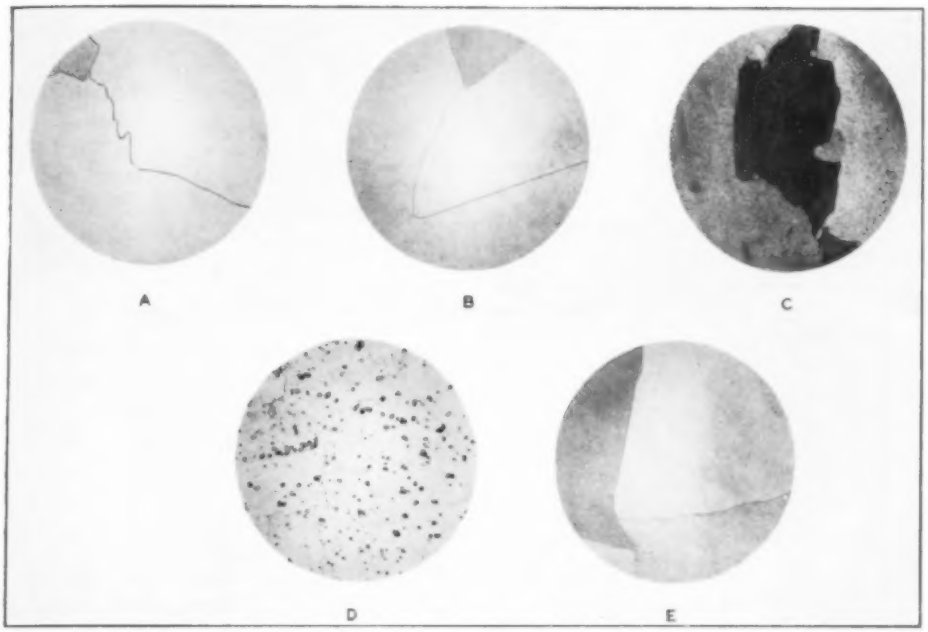


FIG. 11. PHOTOMICROGRAPHS OF LEAD—.04 PER CENT. CALCIUM ALLOY IN THE DIFFERENT HEAT-TREATED CONDITIONS DESCRIBED IN FIG. 10 (ORIGINAL MAGNIFICATION 500×)

(A) SPECIMEN HEATED AT 290° C. FOR 15 MINUTES. SOLID SOLUTION STRUCTURE.

(B) SPECIMEN HEATED AT 290° C. FOR 15 MINUTES, THEN AGED AT 20° C. FOR 24 HOURS. PRECIPITATED PHASE IS SUBMICROSCOPIC IN SIZE.

(C) SPECIMEN HEATED AT 290° C. FOR 15 MINUTES. AGED AT 20° C. FOR 24 HOURS AND THEN AT 100° C. FOR ANOTHER 24 HOURS. MOST PRECIPITATED MATERIAL IS STILL SUBMICROSCOPIC IN SIZE.

(D) SPECIMEN "C" AGED AT 220° C. FOR 12 HOURS. THE NEW PHASE, APPEARING AS SMALL BLACK PARTICLES, IS AGGLOMERATED LEAD-CALCIUM Pb_3Ca.

(E) SPECIMEN "D" AGED AT 290° C. FOR 15 MINUTES. ALL THE SECOND PHASE IS DISSOLVED. STRUCTURE IS AGAIN THE SAME AS "A".

fatigue endurance, is greatly inferior to that of several lead alloys. A photograph, Fig. 8, somewhat enlarged, of a piece of pure lead cable sheath which failed in service is interesting as an illustration. A network of cracks can be seen extending over large areas of the surface. This condition is typical of lead specimens that have been vibrated for some time. In the laboratory we are now able to produce a similar type of intercrystalline failure by subjecting test specimens to alternating stress. Ability to do this has greatly facilitated the study of fatigue resistance. The comparison of fatigue resistance of pure lead and the lead – .04 per cent. calcium alloy as shown in Fig. 7c was obtained in the laboratory by subjecting specimens of these materials to repeated cycles of equal deflection, 650 cycles per minute. Under this particular laboratory treatment, pure lead fails at about 400,000 cycles of stress, whereas the lead calcium alloy frequently remains unbroken after as many as 80,000,000 cycles of stress. Taking into account the very different and much more complicated conditions to which the sheath is exposed in service, it is, of course, probable that the

service life will not show so great a contrast.

The Lead Calcium Equilibrium Diagram

In addition to their practical usefulness, the lead-calcium alloys furnish an excellent subject for illustrating the relationship between age-hardening phenomena and phase change in an alloy. Fig. 9 is a constitutional diagram which shows the temperature at which alloys in the composition range covered undergo phase changes. In this diagram the weight percentage of calcium is plotted against the temperature. The total area of the diagram is divided by curved lines into several areas each of which represents a metallurgically distinct phase. The curved boundary lines are of course experimentally determined by various means which we need not discuss here. Each of these bounded areas represents the range of temperature and composition throughout which the number of components remains constant. For example in the entire area to the right of and below the line BC, the material is found to be a solid solution of calcium in lead in which are interspersed distinct particles of a different substance, namely the compound Pb_3Ca. The nature of the components which characterize each of the other areas is similarly indicated on the diagram.

It can be seen that a lead – .04 per cent. calcium alloy is a homogeneous solid solution in the temperature range from 265° to 327° C. Below 265° C. the compound Pb_3Ca begins to precipitate. The hardening produced is dependent on the amount, distribution and particle size of the precipitate. It has long been recognized that maximum hardening is produced by a definite set of aging conditions which presumably produces the greatest number of critical sized particles. Fig. 10 shows how the tensile strength of a lead – .04 per cent. calcium alloy can be varied at will by heat treatment. The structure of this alloy when subjected to each of the treatments described in Fig. 10 is revealed in the correspondingly lettered photomicrographs of Fig. 11.

Structural Elements

In this paper a brief account has been given of some of the theories proposed in the effort to account for the hardening and strengthening of metals. If we could give an explanation of these processes more adequately we could perhaps devise new ways of treating metals which would give even better physical properties. For this reason, and to fulfil the more disinterested aims of pure science, such a more adequate explanation is greatly to be desired and it is, in many places, being sought.

From the discussion given here, it is perhaps hard to see why such an explanation is so difficult to find. One important reason is that metals consist in general of crystalline aggregates, the individual crystals being, usually, oriented largely at random. Hence the considerations advanced above, as to the character of the structure and physical properties of the individual crystal, must be applied to the more complex system of crystal aggregates before the full story of the metal's behavior can be told. For instance, in this larger analysis, account must be taken of the nature of the resistance to deformation at the crystal boundaries, which under some conditions, at least, have considerable effect on the behavior of the metal as a whole. Another reason is that the atoms, which we have regarded as the ultimate components of metals, are themselves highly complex structures, possessing many properties not clearly defined or understood. Until we know more about the properties of the structural elements, the atoms, it is evident that we can not understand as completely as we wish, the behavior of metals.

SOME LESS WELL-KNOWN LEAD PIGMENTS

By Dr. A. H. SABIN
NEW YORK, N. Y.

WHITE lead is the best known and one of the oldest pigments, and so much has been written about it that the method of manufacture and its uses are commonly understood. The same is true, although less publicity has been given to it, of red lead, which has been made for two thousand years. There are one or two other lead pigments less well known, though in use for a long time, which are of interest. White and red lead are always made from pure refined metallic lead, but the natural ore can be treated so as to make paint material.

The greater part of lead ore is the mineral called galena, in which one chemical unit of lead is united to one chemical unit of sulphur, a dark-blue heavy mineral almost always showing crystalline structure. It is often found mixed with pyrites, minerals which contain iron or copper, or both, also combined with sulphur and very commonly with some zinc ore. Where silver is also present it is almost always in the galena, and in smelting it comes out in solution in the metallic lead from which it is recovered by a later treatment. Some lead ore is free, or nearly so, from silver, though sometimes there is so much that the deposit is called a silver mine rather than a lead mine. Because of these different ingredients in the rocks which the miner takes out of the ground, different processes have to be used in separating them, and when the lead ore is very pure, as it is in some regions, the metal can be obtained easily.

It has been known for many years that in a furnace of suitable design galena may be mixed with certain other common minerals to form a flux or melted slag which will carry off impurities. With coke to make a hot fire, the lead and the sulphur which is with it will burn in the hot oxygen of the air that comes through the fire, to make sulphate of lead, the simplest chemical combination of these three elements.

There is just enough sulphur in the galena to convert all the lead, when both are combined with the right amount of oxygen, into lead sulphate. But in the glowing hot furnace this simple process is not the only one that occurs, and some of the sulphur burns directly with the oxygen—both of them are probably white-hot—and goes off as a gas, sulphur dioxide, the same as the gas which forms when pure sulphur burns in the air. This leaves part of the lead to combine, somehow, with more oxygen, for it must be remembered that more air than is theoretically necessary finds its way into and through this intensely hot fire, and the heat is such that the most refractory fire-brick used for furnace-linings does not last very long. It is no wonder that the chemical action is not kept down to just one regular formula. When pure metallic lead and oxygen unite in a more orderly and better regulated manner they form the well-known compound called litharge, where one chemical unit of lead always unites with one chemical unit of oxygen (generally supplied from the air) and this cools to a yellow powder. But in this kind of a furnace this new lead-oxygen material seems to combine, in a way not well understood, with the lead sulphate, which is what we are especially desirous of forming. It does not show any litharge-yellow color nor does it behave like litharge. The result is a white powder, in which, as nearly as we can make out, the greater part is

lead sulphate; but a considerable and uncertain part is this annexed lead-and-oxygen unknown compound, which apparently is about as much like litharge as a companionate marriage is like the more definite conjugal union. The analytical chemist, like the census-taker, politely calls it litharge, although he knows it isn't. The more scrupulous theoretical chemist calls it the basic lead ingredient, which is true though not very definite. The proportion of this pseudo-litharge in the "basic lead sulphate" may vary from about a sixth to half of the whole, but the operator tries to keep it rather low, preferably about 15 per cent.

We are now just getting through the furnace part of the operation; obviously this new substance must be cooled and settled out of the great current of furnace-gases and partly burned air before we can do anything with it. In the first place, this great current of hot gas, some of which is air that was not burned, much of it the nitrogen which was the greater part of the burned air, and much of it the burned sulphurous gases, all moving rapidly and carrying a cloud of dust which is the solid matter from burning the lead, passes through a long crooked pipe to let it cool from the cooling effect of the outside world. When it has cooled enough so that it will not set fire to cloth, it is forced by blowers into the lower part, what we might call the basement, of a large and high building. In the floor of the main room are holes every few feet apart each way, through which are short metal tubes or thimbles, to which are tied the bottom of long cloth tubes, perhaps thirty feet long, the upper ends of which are tied and are suspended from an upper floor, so that any powder they may contain may, if they are shaken, fall into the basement. These tubes are perhaps a foot and a half in diameter, they are tied with strings around them near the bottom to the tubes which come up through the floor so that they are bags upside down, and this whole outfit is a bag-house. If you look into the great main room you see nothing but these great rows of bags, near but not touching each other. The cooled gases and floating dust which are blown into the basement, coming from the furnace, enter into all these bags and the gas filters out between the threads of the cloth and is discharged into the outside air, but the dust, which is the basic lead sulphate, stays inside the bags. This is called bag-filtering. At suitable intervals the bags are shaken, either by a mechanical beater or by air pulsation produced by reversals of the blowers, and the white-lead sulphate falls through into the basement, where it accumulates in containers until it is barreled and taken away. As it was carried off from the fire as a fume, floating in the swift current of gas, it will be clear that it must be a very fine powder, suitable to be used as a pigment. One of the companies that makes this calls it sublimed white-lead and has copyrighted this name, but the real white-lead has been made for hundreds of years by a very different process and is a basic carbonate instead of a sulphate, and in many countries it is unlawful to call this sulphate by the name of white-lead. Other people call it basic lead sulphate, which is an accurate name, not calculated to deceive any one. It is a valuable pigment, has considerable durability as a paint material, mixes well with oil and with other pigments, and in paint works well in brushing or spraying. It does not appear to be used alone, but is a common ingredient in mixed or ready-prepared paints as it is highly opaque, is cheaper than the real white-lead, for which it is substituted; if not as durable as that it has permanence enough for many uses, since many people do not expect any paint to last more than two or three

years. For interior work its permanence is ample.

It will be observed that in making the sulphate no attempt is made to obtain any metallic lead from the ore. Separating a metal, as iron or lead, in a pure metallic state, from the ore by any fire-treatment in a furnace is called smelting and for different minerals there are varieties of such furnaces. For very pure lead ores a simple one, of rather small dimensions, easily operated, is used. The ore, galena, is mixed with fuel and put into the furnace, which is known as a Scotch-hearth, and air is blown in at the bottom. The heat of the burning mass decomposes the ore, the metallic lead runs out at the bottom and the sulphurous gas, with the carbonic acid gas which comes from burning the coal, escapes at the open top and is carried off through a hood which may be a vent for a row of these furnaces. In the furnace first spoken of, where the object is to make lead sulphate, the construction and arrangement of the draft and combustion space is quite different, because here the desired product is uncombined metal. But even in the Scotch-hearth part of the metal burns into sulphate, and this goes off up the chimney and with it goes a little more of the lead as sulphide and a smaller portion as sulphite, and these, with a little coal ashes and a very little soot, are carried off in the current of escaping carbonic and sulphurous gas and unburned air. Now, there is enough lead in this floating dust to make it worth saving, so the gases are led, exactly as in the other plant, through a cooling system and into a bag-house and filtered, and the dust thus collected is blue basic lead sulphate, or blue lead, or sublimed blue lead. It is of a dull grayish blue color, which appears to be due chiefly to the blue lead-sulphide in it, not an unpleasant color for some purposes, but too dark to be of value in making house-paints. As a pigment it is sold for painting structural steel, and as the total amount necessarily produced is far more than has ever been sold, some high-pressure salesmanship has been used in trying to sell it. The unsold excess, which is most of it, is accumulated, some greasy rags thrust into the heap and set on fire. It is very bulky and contains much air, and there is enough combustible matter, probably lead sulphide, in it to keep the fire smouldering. It is finally reduced greatly in volume and is of a brownish color, due, no doubt, to oxides. This, which is still a mass which may be shoveled, is put into the basic-lead-sulphate furnace first described and finally comes out as part of its product. It can, if more convenient, be mixed in with the charges of the Scotch-hearth furnace from which it came and part of the lead recovered in this way. Some rubber manufacturers, who use such things in making rubber goods, buy considerable amounts of blue lead, and one large manufacturer sells a great deal to the rubber trade, making no serious effort to sell it as a pigment.

It has some good pigment qualities. It is almost immeasurably fine, which is a rare and excellent thing, it mixes perfectly with oil, and the paint generally (but not always) has good keeping qualities. It is very opaque, and will cover as much surface as any good paint, its color is not objectionable in many places—indeed is liked—and its durability, under favorable use, is perhaps one half to two thirds as much as the average of red-lead paint, which may be considered the standard of all structural-metal paints. It requires more oil to make a serviceable paint than red-lead and while this lessens its durability it makes it cheaper by the gallon. The dry pigment is sold rather more cheaply than dry red-lead, and, other things being equal, cheapness is a good thing. But the labor cost of any painting job is generally at least

twice as much as that of paint, and if one paint is better, let us say only a half better, than another, it is more economical to buy, even if the purchasing agent may not think so; in the end he will.

Blue lead, as well as the white basic lead sulphate first described, usually contains some zinc oxide, because the lead ore contains particles of zinc ore, though usually an effort is made to keep this low by selection at the mine or elsewhere. Some lead ores are nearly free from zinc. The blue lead used as a pigment may contain as low as only half a per cent. of zinc oxide, but may be ten times as much, and it has been made from ores rich in zinc to contain 15 per cent. or even more. There is always a little lead sulphite, from 1 to 4 per cent., and the lead sulphide, to which it owes most of its color, usually varies from 8 to 15 per cent. In the basic lead sulphate ingredient of the blue lead pigment, the "basic lead ingredient," which is generally reported as lead oxide, is quite variable, from 18 to 35 per cent., and what is described as lead sulphate is from as high as more than 60 to less than 45 per cent. of the whole.

These wide variations have many causes; the original composition of the ore, which naturally contains zinc, and this zinc is difficult to recover by itself, but as an ingredient of either "blue lead" or the "sublimed white lead" it is accepted by the buyer; then the temperature in the furnace depends partly on the operator; when the air is very damp a great deal more water goes through the furnace than when it is dry, and this affects the kind of chemical action that occurs and the results obtained. In cold windy weather fire burns in a different way than at other times. And above all, the buyer, not knowing what he is getting, accepts variable stuff that he would never take if he were buying definite material like white lead or red lead or zinc oxide, of simple and well-known composition. In using materials of this latter sort there is more of a feeling of certainty.

It has been said that the blue lead sulphate pigment of variable composition is sold as a pigment for use in paint for metal structures. In this use it competes with red lead, a much older and better known material made by all those who produce the by-product blue sulphate, and by many others. It contains from about one half to two thirds as much metallic lead as red lead, and is sold for about two thirds the price. It is made directly from the ore, while red lead is from refined metal. Its sales for paint purposes are probably from 3 to 5 per cent. of the amount of red lead used for paint, perhaps a smaller proportion than that, and while the gross profit on it is more, the cost of selling is much higher. As has been said, the amount sold for all purposes is but a small proportion of its production, so that most of it has to be roasted and reburned into the white sulphate. Part of its ingredients are theoretically unstable, but probably the main popular objection to it is its extreme variability, producing unexpected failures where a previous lot showed favorable results. For other industrial purposes, like the rubber trade, it may be well fitted, because the consumer has a laboratory and finds out in advance exactly how much of each ingredient to put into a batch and thus uses it intelligently.

It is well to say that among people who use metals as such, the term blue lead means pure metallic lead, as distinct from solder, pewter, type-metal or other metals or alloys, and has no connection with pigments. In this sense, again, it is a technical term.

BEYOND THE MILKY WAY[1]

By Sir JAMES H. JEANS, F.R.S.

Our earth is one of a system of nine planets which, together with millions of smaller bodies, asteroids, comets and meteors, circle round the sun; our sun is one of a system of millions of stars which circle about one another; this star-system is one of millions of star-systems—and here, so far as we know, the sequence ends abruptly. These star-systems are the biggest objects known to science; there is nothing beyond them except the great universe itself. They form the largest subdivision of the universe, and it is from this circumstance that they derive their special importance to science.

The star-system which is best known to us is, of course, our own; we call it the Galactic system, because it is bounded by the Milky Way. We get the best picture which modern science can give us of this system, if we think of it as being shaped like a cart-wheel, with the sun perhaps a third or a half way along one of the spokes, and rotating like a cart-wheel. We still do not know the size of the wheel with any approach to accuracy, but its diameter is probably of the order of two hundred thousand light-years. Still less do we know how many stars there are in the whole wheel. It is almost certainly greater than a hundred thousand million, and may quite well be two, three, four or even five times this number. The band of light we call the Milky Way is formed by the combined light of all the stars at great distances from the sun, including those which form the rim of the wheel. The wheel is held together by the gravitational attractions of the different stars of which it is composed. As a consequence, the outermost stars move most slowly and take the most time to perform a complete revolution, just as in the solar system the outermost planets move most slowly and take longest to describe their orbits round the sun. The sun probably moves round the hub at about 200 miles per second, and takes something over 200 million years to perform a complete revolution.

In the early days of astronomy, this was assumed to be the only system of stars in the sky. Then it began to be conjectured by Kant and Herschel that it was only one of innumerable systems. Recent research has confirmed this conjecture very fully. Something like two million such systems can now be observed; they are the objects we describe as extra-galactic nebulae.

A random collection of extra-galactic nebulae seems at first to show a bewildering variety of size, shape, brightness and constitution, but a scientific study soon reduces them to law and order. It soon transpires that size and brightness go together, and that variations in both originate in differences of distance. The nebula which appears small also appears faint; and does both, merely because it is far away. Thus, the faintness of a nebula gives us a measure of its distance; and we can easily get rid of effects which arise from mere differences of distance.

Also we can avoid all complications caused by the different orientations of the nebulae by a very simple artifice; we reject all those which are not seen edge on, and confine our attention to those that are. We can do this quite recklessly, as some two million nebulae can be seen in all.

[1] An Evening Discourse given at the Centenary meeting of the British Association for the Advancement of Science, London, September, 1931.

We have now eliminated all the purely geometrical effects arising from differences of distance and of orientation, and are left with real physical differences of shape and constitution. We find that by far the greater number of our edge-on nebulae can be arranged in a single continuous sequence; it is, in brief, a sequence which begins with spheres and ends with flat discs, although other features besides shape change as we move along it. The nebulae at one end of the sequence consist solely of round, fuzzy masses—even the most powerful telescope shows no stars in these. About half way along, stars begin to appear in the outer edges of the nebulae. Then, further along, come nebulae such as the great nebula in Andromeda, which consist of a comparatively small, central, fuzzy mass, surrounded by vast crowds of stars. At the extreme end of the sequence we have pure clouds of stars such as our own system. The comparison of the cart-wheel remains quite a good one, throughout the second half of the sequence, because the nebulae here generally have a thick central projection, which we may describe as the hub of the wheel, while the rest of their structure is flat. In brief, our sequence is one of nebulae arranged in order of flatness, and this suggests a simple theoretical interpretation of the sequence.

We know how increasing the speed of rotation of a body results in a flattening of its shape. The ordinary Watt governor provides an obvious instance—as the engine runs faster, it flattens out. The sun rotating only once every 26 days is an almost perfect sphere. The earth, rotating more rapidly, but still very slowly, is slightly flattened, so that we usually describe it as orange-shaped. Jupiter rotates more rapidly—once every ten hours—and is much flatter in shape. Finally, astronomical bodies which are rotating very rapidly may be almost completely flat. It is natural, then, to try to interpret our sequence of nebulae as one of the bodies which are rotating at different speeds. And as we know that the speed of rotation of a body increases as it shrinks, it seems likely that we may interpret this sequence of nebulae as one of different stages of development or evolution. If this conjecture is sound, a nebula starting with little rotation at first and shrinking in size would gradually increase its speed of rotation as it shrank, *and would move steadily along the sequence as it did so.*

The way to test this conjecture is to calculate for ourselves how a mass of rotating gas would change in shape as it condensed and shrank. Although the mathematical analysis is not simple, and can not be absolutely precise, it is, I think, fairly conclusive; we find that the evolution of a mass of rotating and shrinking gas would be represented exactly by passage along the sequence.

It is not worth enumerating all the detailed changes which, as theory predicts, would accompany this evolution, but one is worthy of attention. The more highly developed nebulae do not show a uniform distribution of gas in their outer fringes, but an uneven distribution which first forms condensations or knots, and finally develops into separate stars, such as we have already seen in the great Andromeda nebula. Mathematical theory not only predicts this, but enables us to calculate the amounts of gas which would go into each of these condensations; in other words, we can calculate theoretically what the masses of the stars ought to be if our theory is sound. It is gratifying to find that these theoretical masses agree pretty well with the masses of actual stars. We may, then, be fairly confident that this is the way the stars come into being; our sequence of nebular configurations is, in effect, a sort of cinematograph film of the birth of the stars.

We may, then, feel on fairly safe ground in tracing the evolution of the universe back from stars to nebulae, but how did the nebulae themselves come into being? The conjecture which at once jumps to the mind is that the nebulae may have been formed by the same process as the stars; just as the stars came into being as condensations in a tenuous uniformly spread gas—the outer fringes of the nebulae—so the nebulae may themselves have previously come into being as condensations in an earlier mass of uniformly spread tenuous gas. This can never be more than a conjecture, but there are strong arguments in its favor, as we shall now see.

We have already seen how differences in size and brightness between nebulae of the same shape are almost entirely due to a distance effect. In other words, the faintness of a nebula gives us a measure of its distance. This makes it possible to estimate the distances of all nebulae even the very faintest, with fair accuracy. The faintest which can be observed photographically in the 100-inch telescope prove to be at the amazing distance of about 140,000,000 light-years. Dr. Hubble finds that the two million nebulae which lie within this distance are fairly uniformly spaced at about 1,800,000 light-years apart. We can construct a model, by taking apples and spacing them at about 10 yards apart, until we have filled a sphere a mile in diameter. This will use about 300 tons of apples. This sphere is the part of space we can see in the 100-inch telescope; each apple is a nebula containing matter enough for the creation of several thousand million stars like our sun; each atom in each apple is as big as Betelgeuse with a diameter equal to, or slightly larger than, that of the earth's orbit.

The circumstance that the nebulae are fairly uniformly distributed through space certainly supports the conjecture that they may have originated out of a primeval gas spread uniformly through space. Moreover, it can be proved that such a gas would not stay uniformly spread through space but would break up into condensations; and that each condensation would have something like the same mass as the observed nebulae. Or to put the same thing in another way, the primeval gas would break up into condensations at distances apart comparable with the 1,800,000 light-years which Dr. Hubble finds for the average distance of the actual nebulae. Thus, although, from the nature of things, we can never know the truth for certain, there are good reasons for conjecturing that the nebulae came into existence as condensations formed by a primeval gas which was spread uniformly, or at least with some approach to uniformity, throughout space.

Cosmogony presents us with a picture of the evolution of the universe—a cinematograph film—in which big bodies continually break into smaller; the film shows the one forever changing into the many. One primeval gas produces millions of nebulae, each nebula produces millions of stars, each star may, perchance, change into a solar system producing millions of planets, comets and meteors. Even this is not the end of the story, for planets may break up and form satellites, satellites may break up and form rings of miniature moons, such as we see encircling Saturn. The extra-galactic nebulae illustrate the first two chapters in this general break-up—I. Primitive chaos into nebulae; II. Nebulae into stars.

The general breaking-up process of which this is the beginning is in operation throughout the universe. It might be thought that the attractive forces of gravitation would continually draw all the broken pieces together again.

The exact reverse appears to be the case. Not only is the substance of the

universe forever being broken into smaller pieces, but these pieces forever tend to scatter further and further apart.

To take the example nearest home, the earth is forever driving the moon further away, by the agency known as tidal friction. When we watch the waves of the sea being checked by a sea-beach or a headland, we may reflect that their impact is not only slowing down the earth's rotation and so lengthening the day—it is also lengthening the month by driving the moon further away from the earth. Incidentally, it is also, through the solar tides, driving the earth further from the sun, and so lengthening the year as well.

Again, every ray of sunlight that enters our eye carries mass with it; eight minutes previously this mass was part of the mass of the sun. Every second the sun loses more than four million tons of mass, in the form of sunlight and sunheat. As the result of this continual loss of mass, the sun's gravitational hold on its family of planets forever weakens, and these are driven further off into space. The earth's orbit round the sun is not so much like a circle or ellipse as like a coiled watch-spring—a spiral forever receding into the cold and dark of space.

The same tendency affects the galactic system as a whole. The stars of which it is formed continually scatter their mass broadcast in the form of radiation. As they do so, their gravitational hold on one another weakens, so that the whole galactic system forever expands.

And it must be the same with the other star-systems in space. Throughout the universe, all the smaller broken pieces, satellites, planets, stars, are scattering away from one another in apparent opposition to the laws of gravitation.

Still more surprising and sensational is the recent discovery that the largest pieces of the universe—the great extra-galactic nebulae we have been discussing—are to all appearances engaged in a similar scattering. They, too, appear to be running away from us and from one another. Until recently, it was thought that on the whole the nearer nebulae were approaching the galactic system, while the more remote were receding. We now know that the nearer nebulae appeared to be approaching merely because they happen to lie mostly in the direction towards which the sun is being carried by the rotation of the galaxy; actually we are approaching them. After the sun's motion in the galaxy has been taken into account, all, or nearly all of the nebulae appear to be receding from the galaxy. The nearer nebulae have small speeds, and the more remote nebulae have greater speeds; in general, speed is approximately proportional to distance. This simple law seems to hold to the very furthest of the nebulae—Hubble finds that for every million light-years of distance there is a speed of recession of about 105 miles a second. The last nebula to be investigated at Mount Wilson shows a speed of recession of 12,300 miles a second; its distance, as estimated from its faintness, being about 105 million light-years.

On the face of it, this looks as though the whole universe were uniformly expanding, like the surface of a balloon while it is being inflated, with a speed such that it doubles its size every 1,400 million years.

One of the great puzzles of astronomy at the present moment is whether these apparent motions of recession are real or not. They are deduced from spectroscopic observations; the nebular spectra show displacements to the red, which, interpreted in the most obvious way as Doppler effects, give the speeds already mentioned. Yet every spectroscopist knows that many factors besides mo-

tions of recession are capable of reddening light.

There is one strong theoretical argument in favor of regarding the apparent speeds as real. Einstein's original cosmology regarded the universe as being as full of matter as a universe of its size could possibly be without violating the theory of relativity. Recently, Lemaître, of Louvain, has shown that a universe of this type would not be static—there would be an unstable quality about it. The condensation of the primeval gas into distinct nebulae, and the imprisonment of a large part of the free energy of the universe in these nebulae would cause it to start expanding, in which case it would continue to expand, its radius finally increasing exponentially with the time, until it ended up as an empty universe—finite matter spread through infinite space. Throughout the motion, the relative speed of recession of any two nebulae would be exactly proportional to their distance apart, so that, at first glance at least, this theory seems exactly to fit the observed facts. It not only provides a suggestion as to why the nebulae may be receding. It goes much further and predicts that they must be receding; if Einstein's relativity cosmology is sound, the nebulae have no alternative—the properties of the space in which they exist compel them to scatter.

Yet various circumstances suggest a need for caution. For one, the speeds of the nebulae are not strictly proportional to their distances, and it is not easy to explain the discrepancies, which do not look like mere random motions. Again, the very magnitude of the apparent speeds casts doubt on their reality; they would reduce the whole existence of the universe to a mere flash—at any rate in comparison with what we have recently believed. If they are real, Eddington has calculated that the universe must have started from a radius of about 1,200 million light-years, and that its total mass must be about 2.3×10^{55} grams, which is the mass of 1.4×10^{79} protons and an equal number of electrons. So far as we can tell from the masses of the extra-galactic nebulae, the present average density of matter in space appears to be not less than 10^{-30} grams per cc, which, with the same amount of matter, would assign a radius of 13,200 million light-years to the universe—only eleven times its initial value. If, then, the motions are real, the universe is only at the beginning of its career: it can not have doubled many times since it started. And as it appears at present to be doubling in size every 1,400 million years, the few doublings which these figures permit can not have occupied more than 10,000 million years at most.

General calculations on the ages of astronomical bodies point to far longer periods of time than this. The mere act of condensation of the nebulae—the occurrence which seems most likely to have started the expansion—was probably a matter of hundreds of thousands of millions of years. Perhaps there is no real difficulty here; it might well take this long to get the doubling process really going—indeed, Lemaître has calculated that it would take some such time. The real difficulty is that the stars carry intrinsic evidence of having lived through far longer periods than this. Both single stars and binary systems show an approximation to equipartition of energy which must have taken far longer than this for its establishment.

Spectroscopic binaries provide further evidence. These consist of pairs of stars revolving around one another. Observation reveals a complete sequence; it begins with systems which appear to have just broken into two as the result of rotation—pairs of stars describing circular orbits, and almost in contact—and ends with systems in which the two stars

are far apart and describing elliptical orbits. Theory suggests that this observational sequence exactly depicts the evolution of a star which has broken into two as the result of excessive rotation. The outstanding importance of this sequence to our present discussion lies in the fact that the stars at the beginning of the sequence are undoubtedly many times more massive than those at the end. It seems likely that those which are now at the end must have begun at the beginning and lost the greater part of their mass in the form of radiation, and to do this would take millions of millions of years. Considerations such as these make it very difficult to believe that the universe can be such an ephemeral concern as the apparent speeds of recession of the nebulae would suggest. There is, I think, every reason to hope that within a very short time we shall know the truth about this puzzle, and, whatever the solution may be, there seems to be a considerable chance that it may provide us with a clue, perhaps even with a key, to the structure of the universe as a whole. Until quite recently, the scientist, like the ordinary man, accepted the fundamental ingredients of our experience—space, time, matter and energy—more or less at their face value. The most obvious and superficial interpretation suggested by every-day experience was assumed to correspond fairly closely to ultimate reality. The theory of relativity has shown that we were utterly wrong about space and time, and we are beginning to suspect that we are still just about as far wrong about matter and energy. The concept of an expanding universe may prove after all to be a false scent, and the truth may lie in some other direction. In either case the observed phenomena must mean something, and their true interpretation, when it is found, may carry us a step on towards the solution of the greatest mysteries of the external world—the nature of space, and of time, matter and energy, and of the combination of all these which constitutes the physical universe.

THE FUNDAMENTALS OF THE RELATIVITY THEORY[1]

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NEW YORK, N. Y.

Introductory Remark

The rumor that only a dozen people in the whole world understand the relativity theory is a myth. Competent physicists comprehend the theory and their number is certainly more than twelve. What is true about that rumor is that even highly educated non-physicists know very little of the theory. The reason for this is that its essentials have never been explained in a manner intelligible to a layman. No treatise, scientific or popular, states clearly and saliently the new fundamental ideas, previously unknown, from which the theory was deduced. Educated laymen know that Copernicus discovered the revolution of the planets around the sun; Newton, the mutual attraction of the bodies, etc. But ask a layman what discovery of Einstein's led to his theory and he is at a loss for an answer. It is true, the answer to the question is contained in the better treatises on the theory, but even there it is so entangled in a mass of particulars, uninteresting to the layman, that he is unable to unravel it. To impart to him a fair understanding of the relativity theory the discovery underlying it should be clearly stated right from the start and the encroachments of philosophy and fancy upon it should be avoided throughout. It is a purely physico-mathematical subject and must be treated as such to be comprehensible. The mathematics required in the special relativity theory, which is the foundation of the general one, is quite simple, well intelligible to the average educated laymen. An attempt to explain the theory without touching in the least on mathematics is bound to fail of its purpose.

[1] When I was studying medicine in Munich good fortune brought me in contact with Albert Einstein, then ten years old. For five years I associated with him intimately and frequently. Thus I had the opportunity for observing at close range the extraordinary mentality which Albert manifested already at that young age. I even played a part in its unfolding during that period. I acquainted him with a popular book on physics which exerted a great influence on his whole development. I gave him the first book on mathematics and helpful advice in solving the first geometrical problems. When he was about 13 years old, the flight of his mathematical genius was so high and swift that I could no longer follow. Philosophy then became a subject of our conversations. I advised him to read Kant. The works of this philosopher, incomprehensible to ordinary mortals, seemed to be clear to the young schoolboy. When I made those observations, the thought was often present in my mind that a great scientist would develop out of that child. The expectation has been richly fulfilled. (For a more detailed account see New York *Times*, February 10, 1929. Special Features, p. 11.)

Discovery Underlying the Relativity Theory, Relativity of Simultaneity

Einstein discovered the relativeness of the simultaneity of distant events. To appreciate this discovery, which forms the origin of the relativity theory, we have to know what is meant by the simultaneity of distant events. Two events that are far apart in space are simultaneous or non-simultaneous according to whether an observer stationed in the middle of the distance between them perceives them at the same instant or at different instants. This definition of simultaneity takes for granted that light travels equally fast in all direc-

tions. Since the observer is equally distant from the two events, the light coming from one of them needs as much time to reach him as that coming from the other.

Two distant events simultaneous for an observer in one system, for instance, in a very long ship traveling with uniform speed in a straight line, are non-simultaneous for one observing them from another system, for instance, from the river shore along which the ship is moving. In other words, the simultaneity of distant events is not absolute, but relative, that is, dependent upon the system from which they are observed. Einstein made this discovery and recognized its vast importance for physical research. Its greatness lies in the fact that that thing, simultaneity, did not attract the attention of anybody and he first took notice of it and saw its full import, just as Newton found great significance in a trifle, the fall of an apple to the earth. Let us see now how the relativeness of simultaneity was established.

A ship travels on a river with uniform speed and without noticeable vibration and noise. The water is smooth, the air still. The shore forms a straight line. Under these conditions the passengers are not aware of any motion of their system, the ship, as long as they do not look at its surroundings. When they do observe the shore, the ship is still at rest for them, only the shore is moving from bow to stern. All actions they may perform do not reveal to them any motion of the ship since they proceed exactly in the same manner as on the earth. For an observer on the shore, however, the ship is moving in the direction from stern to bow.

On the top deck of the exceedingly long ship midway between stern and bow is an observer S. In an angle mirror he can see a pole attached to the stern and another pole fastened at the bow. The former carries a white electric lamp (W) and the latter a green one (G). Mr. S turns a switch and the lamps light up. Two events take place, a white flash and a green flash. If S sees them at the same instant in his angle mirror, they are simultaneous for him according to the definition given above.

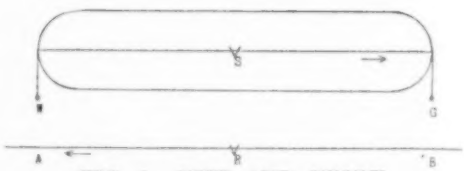

FIG. 1. SHIP AND SHORE

G, GREEN LAMP AT THE BOW; W, WHITE LAMP AT THE STERN; S AND R, OBSERVERS WITH ANGLE MIRRORS.

On the river shore is another observer R. In an angle mirror he can see the two lamps on the ship. At the instant of their lighting up R is opposite S or midway between the white light (W) and the green one (G). He sees the two flashes but G later than W. The rays from G and W need some time to reach him. Since he moves away from the green ray and toward the white ray—remember that the shore moves from bow to stern—the green ray needs more time to reach him than the white ray, and is therefore seen later. The flashes are perceived by observer R at different instants and he was midway between them when they occurred. Hence they are non-simultaneous for him according to definition.

One can easily compute the amount of the non-simultaneity of the two flashes for observer R. For this purpose we assume greatly exaggerated measures. The ship is 1,000 kilometers long and its speed is 10^5 km. per second. A simple calculation gives the following results. Observer S sees the flashes 1/600 of a second after their occurrence. Observer R sees the white flash 1/800 second after its occurrence and the green flash 1/400 s. after its occurrence. The two flashes are non-simultaneous for him by 1/800 of a second.

The relativeness of simultaneity

proved above has its cause in the circumstance that we do not perceive events directly but indirectly through the light coming from them and light needs time for its propagation. From the stipulation that it travels equally fast in all directions the relativeness of simultaneity follows as a logical consequence.

The Relativity of Time and of a Spatial Length

The relativeness of simultaneity led Einstein to the discovery that time and a spatial length, too, are relative, that is, different for different observers. This was all the more amazing since time and space were always considered as absolute. No less an authority than Newton emphatically affirmed the absoluteness of time and space which, as he expresses it, have no "reference to any external object."

For the sake of clearness in the further discussion of our subject, attention is called to a point nowhere mentioned, and this is that "time" denotes two things which are not identical, to wit, a duration, *i.e.*, an interval between two events, as in the statement "he traveled three hours," or an instant, as in the statement "he arrived at midnight." An instant and an interval are in time what a point and a length are in space. In the prerelativistic era an interval was considered to be absolute. For instance, if two flashes occurring on the ship are separated by a second as determined by a clock on the ship, it was taken for granted that for an observer on the shore the flashes are also separated by a second of his clock. Einstein discovered that this is not the case, that the observer on the shore finds the interval between the flashes to be more than a second by his clock, *i.e.*, that an interval is relative.

An interval of time stands in connection with the rate of a clock. It follows that the latter, too, must be different for different observers. Einstein found that a clock in motion relative to an observer has for him a slower rate than an equal clock which is at rest relative to him. This may be illustrated as follows. Our ship departs exactly at noon as indicated by a clock on the ship and an equal clock on the shore. After some time observer S finds that his clock is 15 minutes past 12. At this instant the shore clock, as can be proved, has not yet reached for him 15 minutes past 12, but is somewhat behind, let us say, 14 minutes past 12. Conversely at 15 minutes past 12 by the shore clock observer R finds the ship clock to be only 14 minutes past 12, one minute too slow. That all this holds true will be proved later. It follows that both an interval and an instant are relative. An interval of 15 minutes for one observer is only a 14 minutes' interval for another; the instant 15 minutes past 12 for one is 14 minutes past 12 for the other.

Finally a spatial length, absolute according to Newton, has been found by Einstein to be relative, to have a smaller value for an observer relative to whom it is in motion than for another observer relative to whom it is at rest.

Two Hypotheses and Definition of the Special Relativity Theory

The factors unknown before and fundamental for the relativity theory are the relativeness of simultaneity, the retardation of a moving clock and the shortening of a moving length. We have proved the first factor but not the other two which imply the relativeness of time and a (spatial) length. The latter proof follows from two hypotheses which form the essential part of the relativity theory.

Certain physical experiments, notably that of Michelson and Morley, gave results which were at variance with firmly

established theories. These discrepancies could not be explained and caused no mean perplexity to physicists. Einstein found that two hypotheses furnish the solution of the difficulty. One of them he called the "relativity principle" and the other the "principle (or law) of the constancy of the velocity of light."

(1) *Relativity Principle.* The laws (mathematical equations) for all natural phenomena without exception are the same (have the same form) in all systems which are in uniform rectilinear motion relative to each other. Two implications are contained in this principle. First, all such systems are equivalent for formulating the law of any natural process. Second, by no means is it possible to ascertain absolute uniform rectilinear motion of a system.

(2) *Principle of the Constancy of the Velocity of Light.* Light travels *in vacuo* with the constant velocity c (3.10^5 kms) in all directions independent of the motion of its source. This principle implies that a ray of light has the same velocity c for all observers irrespective of their motion relative to each other.

Between the two principles there was a contradiction, as we shall soon see, owing to the traditional absoluteness of time and a length. Einstein subjected these concepts to a critical examination and found that time and a length are relative. Thereby the conflict between the principles disappeared. The theory which he developed thereupon, harmonizing them, is the "Special Relativity Theory." The term "special" indicates that it is restricted to systems in a special kind of motion, namely, in uniform rectilinear motion. Later he extended the theory to apply to systems in any kind of motion, *i.e.*, also in accelerated and rotary motion. This amplified theory is the "General Relativity Theory."

Addition of Velocities according to Classical Mechanics and Conflict between the Two Principles of the Relativity Theory

On the deck of our ship moving with the velocity v, a ball is rolled from stern to bow with the velocity u. What is the value of the ball's velocity U for the observer on the shore? If the ball is at rest on the deck for a second, it travels in this time past observer R the distance v because of the ship's motion. When it rolls, it proceeds for observer S in a second the distance u, hence also the same distance for observer R. Altogether it moves therefore for the latter in a second the distance $u+v$. This sum represents the ball's velocity for observer R: $U=u+v$. Accordingly the velocity sought is obtained by adding the velocities given. This is the mode of the addition of velocities in classical mechanics. It creates a conflict between our two principles. For the preceding considerations must be valid just the same if the ball is replaced by a ray of light. We have then to use c instead of u and we obtain: $U=c+v$. This means that the velocity of the ray is $c+v$ for observer R while for observer S it is c. This contradicts the relativity principle according to which the law of light propagation must have the same form for both observers, can not have the form c for one and the form $c+v$ for the other.

This dilemma disappears when the addition of velocities according to classical mechanics is given up. It is based on the absoluteness of time. It assumes that a second on the ship is also a second on the shore or, generally, that a time interval determined by a clock on the ship has the same value when measured by an equal clock on the shore, *i.e.*, that $t'=t$. But the equality

of t′ and t is an unproved traditional notion. If we abandon it and establish another relation between t′ and t, we find that the same ray of light has the velocity c for both observers. This relation is given through the equation: $t' = tq$, wherein $q = \sqrt{(1 - v^2/c^2)}$. We shall see that from this equation follows that $U = c$, *i.e.*, that a ray of light produced on the ship has the velocity c also for the observer on the shore.

Transformation of Coordinates

The systems ship and shore being inappropriate for general considerations, we must now resort to systems of coordinates. A Cartesian system of coordinates is a frame consisting of three straight lines intersecting each other at right angles in one point, the zero-point. Given such a frame, any point in space can be located through its distance from the zero-point on each axis of the system. The three distances are the space coordinates of the point. To determine an event occurring in it we need to know the time of the event. It is given through a clock at rest in the system. The four variables of an event are designated with the small letters x, y, z, t.

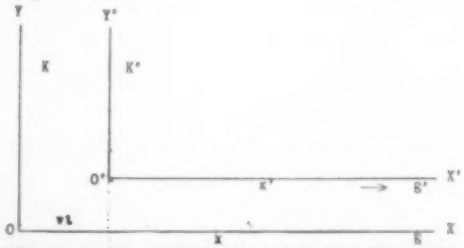

FIG. 2. TWO SYSTEMS OF COORDINATES WITH CORRESPONDING AXES PARALLEL.

We consider two such systems K and K′ with corresponding axes parallel and K′ in uniform rectilinear motion relative to K with the velocity v and in the direction of the positive X-axis. An event may occur on the X-axis of K and its variables in this system may be given. What are its variables in K′? Since the event takes place on the X-axis, the variables y and z may be neglected. The question is now, what are the variables x′ and t′ for an event in K when its variables x and t are given?

According to classical mechanics the relations between the two sets of variables are given through these equations:

I, (1) $x' = x - vt$; (2) $t' = t$.

They are called the Galilei-transformations. The relativity theory rejects them. According to it a ray of light must have the same velocity c in both systems. This is the case when the relations sought are expressed through the following equations, called the Lorentz-transformations:

II, (1) $x' = (x - vt)/q$;
(2) $t' = (t - vx/c^2)/q$; $q = \sqrt{(1 - v^2/c^2)}$.

The deduction of these equations is quite simple.

Addition of Velocities according to the Relativity Theory

The equation $U = u + v$ for the addition of velocities in classical mechanics follows from the Galilei-transformations. The ball proceeds in t′ seconds of a clock on the ship the distance $x' = ut'$. If we replace x′ and t′ by their values from the Galilei-transformations, we obtain $x - vt = ut$; $x = t(u + v)$. If t is one second by a clock on the shore, x becomes U, and we obtain: $U = u + v$.

But if we replace x′ and t′ of the equation $x' = ut'$ by the values from the Lorentz transformations, we arrive at a different formula for U. We have then: $(x - vt)/q = u(t - vx/c^2)/q$; $x(1 + uv/c^2) = t(u + v)$. If t is one second by a clock on the shore, x becomes U and we obtain: $U = (u + v)/(1 + uv/c^2)$. This equation is the theorem of the addition of velocities in the relativity theory.

If we replace the ball by a ray of light, u becomes c and for the velocity of the ray relative to the shore we have the equation: $U = (c + v)/(1 + cv/c^2) =$

$(c+v)/(c+v)/c=c$. This equation shows that the velocity of light can neither be increased nor diminished. For when v is negative, U has also the value c: $U=(c-v)/(1-cv/c^2)=(c-v)/(c-v)/c=c$. The ship's velocity does not enhance nor reduce the light's velocity. Hence a ray of light necessarily has the same velocity for the observer on the ship and the one on the shore.

The two principles of the relativity theory are now in accord since we have furnished the proof that light has the same velocity c for any two observers. We have still to show that time and a length are relative. For this was taken for granted in that proof.

Definition of Time

Time has been defined by Einstein as "the position of the little hand of my clock." This determines time as an instant. But since two instants fix an interval, the definition determines also time as an interval.

The definition is adequate for finding the time (instant) of an event happening near the clock but not for a temporal connection between two events remote from each other. In the latter case we need two clocks that have the same rate, are synchronous. Einstein devised an ingenious way of synchronizing two distant clocks A and B through light signals. The stipulation (not assumption) is made that light travels from B to A as fast as from A to B. At 30 seconds past 12 by the A-clock a light ray is sent from A to B. It is reflected from B at 32 seconds past 12 by the B-clock. The two clocks are synchronous if the ray returns to A at 34 seconds past 12 by the A-clock. For since $32-30=34-32$, the light has traveled equally fast in both directions and the stipulation is fulfilled. We have to express all this in general terms. The departure of the ray takes place at the instant t_a of the A-clock, the reflection at the instant t_b of the B-clock, and the return at the instant t'_a of the A-clock. The two clocks are synchronous if $t_b-t_a=t'_a-t_b$. The equation is the definition for the synchronism of two distant clocks at rest relative to each other. The clocks are non-synchronous if the two sides of the equation are unequal. Any number of distant clocks at rest in a given system (ship or shore) can be synchronized in the manner described. We have now gained a definition of time adequate for a temporal correlation of distant events. The time (instant) of an event in a system is the hand-position of a near-by clock at rest in the system and synchronous with a definite clock also at rest in the system and used in it for all determinations of time.

Proof for the Relativity of Time and of a Spatial Length

We can now prove that clocks synchronous for observer S in system K′ are non-synchronous, a clock in K′ is retarded, and a length in K′ parallel to the X′-axis is shortened for observer R in system K which is in motion relative to K′ with the velocity v, *i.e.*, that time and a spatial length are relative. The proof for these three contentions follows from our two principles. We give it here for the first one.

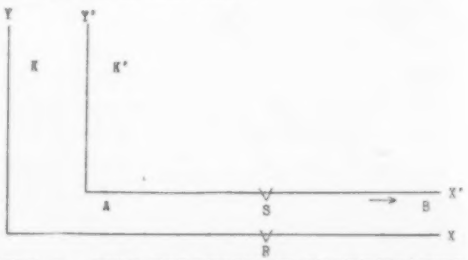

FIG. 3. TWO SYSTEMS OF COORDINATES WITH CORRESPONDING AXES PARALLEL

A AND B, CLOCKS SYNCHRONOUS IN SYSTEM K′.

At the points A and B of the X′-axis are clocks synchronous for S. The other observer R on the X-axis perceives their hands through light illuminating their

dials. He notices that at the instant t_a of the A-clock a light flashes up at its dial, is reflected from B at the instant t_b of the B-clock and returns to A at the instant t'_a of the A-clock. The light ray travels towards B with the velocity c for observer R just as for observer S (relativity principle). But for the former the B-clock flees from the ray. The velocity with which the ray overtakes the clock is therefore diminished, only $c-v$. The distance covered by the ray is AB, hence the time consumed in the travel is $AB/(c-v)$. Observer R obtains therefore the equation $t_b - t_a = AB/(c-v)$. At the return the ray has again the velocity c for observer R (law of light propagation). But A moves towards the ray for him, hence the velocity with which the ray reaches A is increased for him, namely, $c+v$. The distance covered is again AB. Observer R finds therefore for the time of the return the equation $t'_a - t_b = AB/(c+v)$. From the two equations follows: $t_b - t_a > t'_a - t_b$. The two clocks are therefore non-synchronous according to the definition for the synchronism of two distant clocks.

The retardation of a clock and the shortening of a length are demonstrable by the same method. It is to be noted that both principles are needed in the preceding proof.

Summary of the Fundamentals of the Special Relativity Theory

The Special relativity theory consists of two hypotheses and several inferences. For the sake of brevity in summarizing them it is stated that K and K′ mean two systems of coordinates in relative uniform rectilinear motion in the direction of the positive X-axis and R signifies an observer at rest in K and S one at rest in K′.

I. Hypotheses. 1. Relativity Principle. The laws of nature are alike in all systems, in K′ and in K. 2. Law of Light Propagation. The same light ray travels with the velocity c for all observers, for S and for R.

II. Inferences.

1. Two events simultaneous in K′ for S are non-simultaneous for R: simultaneity is relative.

2. Two clocks synchronous in K′ for S are non-synchronous for R.

3. A clock in K′ is retarded for R, has a slower rate for him than his clock.

4. An instant indicated through a clock in K′ is found by observer R to be indicated differently through his clock: time as an instant is relative.

5. Observer R finds an interval between two events in K′ as indicated by a clock in K′ to be too short; he obtains a larger value for it by his clock: time as an interval is relative.

6. A length in K′ parallel to the X′-axis is shorter for R than for S: the value of a spatial length is relative.[2]

Conclusion

The equations or formulas called the Lorentz-transformations comprise every one of the six inferences from the two principles and are deducible in a manner well intelligible to the average educated layman. Acquaintance with the deduction and interpretation of these formulas gives the reader a better comprehension of the relativity theory.

[2] The manuscript of this essay was read by a competent physicist who has made valuable contributions to the relativity theory, Dr. R. A. Wetzel, of the New York City College (''The New Relativity in Physics,'' *Science*, October 3, 1913.) He approved of the work and called the writer's attention to a book published recently by an opponent of the theory. One of the arguments of this author against the theory is that it makes time and length ''relative by definition'' and this definition is arbitrary. The writer finds it necessary, therefore, to emphasize that the relativeness of time and length embodied in the inferences enumerated above is not a matter of definition in the theory. They are relative not because ''they are defined to be so'' but because their relativeness is a cogent conclusion from the two fundamental principles of the theory.

For a still broader knowledge of it he needs information on other items connected with the theory. We can merely mention the most important ones: the observations and experiments which gave the incentive to the development of the theory; notably the experiments of Fizeau and of Michelson and Morley; the consequences of the special relativity theory, such as the union of mass and energy; the equality of inertia and gravitation and the general relativity theory; the consequences from the latter, such as the bending of a ray of light, the anomaly of the planet Mercury, the shifting of the spectral lines of sidereal light; the erroneous popular notions regarding the ether, the fourth dimension and the Euclidean geometry, etc. All these subjects are treated in a book to be published later which follows the method used in this essay. The latter is an extract of the former and intended merely to impart to the lay reader an understanding of the fundamentals of the relativity theory.

IN QUEST OF APOLLO'S SACRED WHITE MICE

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A SNOWY mouse with claret colored eyes is actively tearing paper in her cage upon my desk. She is merely a "tame, white mouse" and but one among millions of her kind raised for scientific study throughout the world to-day. I have been watching her and I have been thinking. In my reaction to her, there is nothing original, because many a man in the past has had his curiosity aroused by just such an albino mouse. Aristotle mentioned a current saying to the effect that the white mice of Asia Minor ruminate. Pallas observed that when white mice are mated to whites all their offspring are albinos like their parents. Darwin learned that whenever white mice are mated to grays there are grays among the immediate progeny and both whites and grays in later generations. Mendel crossed white mice to gray ones, and his biographer suggests that the results of these unpublished experiments may have led him to formulate his theory of heredity for which he later provided overwhelming proof by his classical experiments upon garden peas.

The white mouse has stimulated in me an interest in her origin, and from the data which I have collected we may piece together something of that story.

Some of her past lies hidden away—a bit here, a bit there within a few curious parchment bound volumes of classic tongue, now treasured solely for their great age. Much of the rest is buried forever in the dust that was Babylon and Troy.

Beyond the antiquity of three millennia, at the dim dawn of human record where fact and fiction inseparably commingle, there we must begin if we would trace her lineage. It does not require a great flight of fancy to picture that scene of domestic commotion in the light of a pine-knot fire when the first frightened white mouse was seen by a cave woman to dart from an uncovered grain jar to a crevice in the corner. The woman gave a gasp and excitedly described what she had seen in terms of snow and lightning, only to be squelched by one of the cave men who gruffly assured her that she was imagining things

[1] The field investigation herein described was provided for by an appointment from Harvard University as Sheldon Fellow in Biology for the year 1930.

again. But when the mouse reappeared from time to time and was seen by other members of the family, the tottering patriarch of the cavern declared *ex cathedra* that it was a good spirit which had come to dwell with them and that its presence in the cave would make them prosper. Whether or not this description bears any relation to the truth, no one can tell, but we do know that somehow white mice found their way definitely into the religious auguries of China, Babylon and Troy, possibly also Carthage, Alexandria and Philistia.

Among Germanic tribes the goddess of fortune appeared as a white mouse. The Slavs and Romans considered it a good omen, while in Japan to-day it is the symbol of Daikoku, the god of wealth.

About 1,400 years before Christ, Teucer and his followers landed upon the shore of Asia Minor just below the Dardanelles for the purpose of colonization. Tradition has it that before these Cretans set out from their home land they had been given an oracle commanding them that where they settled there they should build a temple to Apollo, in which shrine they should worship the "earth-born creatures." Now to the nature-adoring ancients each animal had symbolic significance. Witness the popularity of the python cult in Crete. Witness the gifts which the surrendering Scythians presented to Darius to show his complete possession of all they had owned. They sent him a mouse, a frog and a bird, symbolizing their land, sea and sky, respectively. The choice of the mouse by the Trojans as the sacred symbol of Apollo is explained by the following Pontic legend:

For a long time the invading Teucri were restricted to the shore by the aboriginal Pontians, with whom they continuously contested in arms. A decisive victory for the Cretans was accredited to the mice which their Apollo caused to gnaw the leather from the shields of the enemy during the night preceding the final battle. After conquering Pontus the colonists toiled many days to erect by the winding brook Scamander the high-walled Pride of Priam. Nor did the Trojans forget in their prosperity the humble source of their salvation, but in gratitude they constructed upon the adjacent Isle of Tenedos their first temple to Apollo, a smintheon, where mice were sacrosanct.

Several Greek and Roman historians visited the Troad temples and described in detail a marble sanctuary teeming with gray mice raised at public expense. More holy than all the rest were a family of white ones having their nest under the altar itself. Coins of the Troad frequently bear representations of the archaic cultus statue of Apollo Smintheus and occasionally a sacred mouse.

Apollo Smintheus, besides being god of the bow, had among his dominant attributes soothsaying and healing. It was to Herophila, sibyl of the Mouse Apollo, that Queen Hecuba turned in despair for the interpretation of her dream forecasting the collapse of Troy and the fate of herself and family. Possibly, Herophila consulted the white mice, which method of augury had long been practiced in Babylon and made known in Asia Minor through contact with the Persians. During the life of Christ the mice raised in the temple were used extensively for purposes of prognostication, and Pliny records that if there be many white ones bred, it is a good sign which predicts coming prosperity. He recounts also the alleged observation of soothsayers that the size and "numbers of the filaments of their liver and bowels wax and wane with the moon."

The healing qualities of mice were early exploited by the priests of Apollo, and the devout often carried temple

A B

APOLLO SMINTHEUS APPEARS UPON COINS OF ALEXANDRIA TROAS (A) AND TENEDOS (B). THE LATTER SHOWS A SACRED MOUSE

mice into their homes in time of sickness. The mere presence of a sacred mouse in the sick room effected a cure. A story goes that if the curative mouse were not returned to the temple, it would find its way back of its own accord. Galen prescribed equal parts of cock's gall, mouse blood and woman's milk dried and powdered as a cure for cataract. Pliny said that a poultice made from a freshly killed mouse was an excellent remedy for snake bites. The Romans employed mouse dung in the treatment of baldness. The "Father of Medicine," Hippocrates, was born far south of the Troad at Cos, an island extolling the greater virtues of the serpent. His scepticism is evident. He says that he did not even go to the trouble of testing the virtue of mouse blood for warts, prescribed by his colleagues, because he had a magic stone with lumps upon it which had already proved to be an efficient remedy.

Murine formulae, probably of Greek origin, appear from time to time in the writings of the middle ages. St. Hildegard of Bingen recounts that mice are a cure for epilepsy. The manuscript known as Picatrix endorses fumigation against disease with a smudge prepared from 14 bats and 24 mice. Peter of Albano employs mouse dung as a cure for poisons. As a present-day hangover of medieval black art may be cited the occasional feeding of stewed mice to children in Boston and New York to prevent bed wetting. This cure is prescribed in London Pharmacopoeia of 1667. Peasants of Switzerland recommend that a stewed mouse be eaten every two weeks in order to prevent toothache. The persistent local impress of the Sminthian cult is evident in that modern Greeks call mice "pontiki" (from the Trojan region of Pontus), and both Turks and Greeks alike prepare "mouse oil" as a panacea for human ailments. Nearly all variations of the formula agree that about 10 newborn mice must be dropped into a liter of olive oil and allowed to dissolve a fortnight in the sunshine with occasional shaking. At Keyekli, opposite Tenedos and about 10 miles from the mound of Troy, the Turks add as necessary ingredients the flowers of two small composites (*Artemisia arborescens* L.) one yellow and one white. The white one is said to be the more potent. On the Island of Chios only one flower is used. In Constantinople no flowers are necessary. A Cretan informed me that in some parts of his land the young of an albino mouse are much superior to the common gray variety, while a more heretical Cretan confided secretly his candid opinion that old olive oil lacking the mice and herbs was almost as effective.

The sacred white mice of Pontus are mentioned in the writings of Aristotle, Strabo, Aelian and Suida, while other writers such as Pliny, Hesychius, Albertus, Apostolius, Gesner, Johnson, Pallas and Darwin speak of the albino variety in general.

So strong became the cult of the mouse god that centers of worship were located at Chryse, Killa, and Tenedos, Alexandria, Hamaxitos, Larissaia, Parion, Arisba, Methymna and Magnesia.

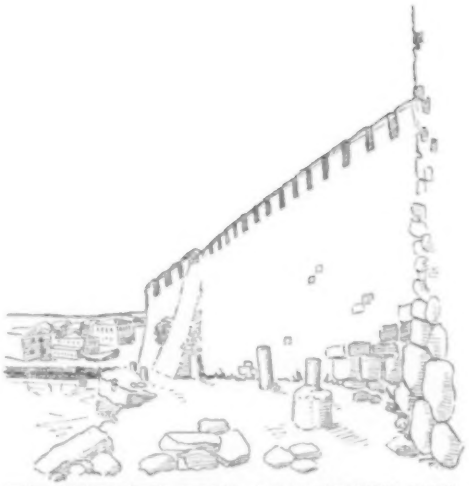
With the mouse cult at the height of its popularity in the spheres of prophecy and therapeutics the loquacious St. Paul set out upon his missionary journey

through Asia Minor vehemently denouncing local religious practices wherever he went. In order to avoid difficulties, the Holy Ghost wisely suffered him not to go into Bithynia nor to preach in Asia (Pontus), two regions where men worshipped the ancient mouse god. Twice he sailed in silence past the famous mouse temples on the mainland and those upon the islands of Mitylene and Tenedos. But upon his return from Athens, however, St. Paul was so pent up that he could stand it no longer and indulged himself by delivering an all-night sermon at Alexandria Troas against the Holy Ghost's orders. Then, perchance, to avoid Apollo's irate priests at the wharf from which his boat was scheduled to sail in the morning, he retreated over a back-road to the town of Assos (Beiram), where he had previously arranged that his comrades on the boat should pick him up.

The mouse god was so deeply rooted in the Troad that it may not have been Christianity at all but rather Mohammedanism that overthrew Apollo Smintheus as a local god and wrecked the last of his shrines at the time of the Turkish conquest. By this time white mice had appeared in the monastic writings of Europe.

But are we to conclude that the active creature upon my desk is really a descendant of Apollo's sacred mice?

We can not be sure of the sources of information drawn upon by Pliny, Allianus, Suida or Albertus. Aristotle was of Ionian stock and doubtlessly visited nearby Pontus. Strabo definitely inspected a Sminthian temple, perhaps at Alexandria Troas. Apostolius was born in Constantinople and probably traveled in the Troad. The later historians appear to be writing of white mice raised in cages in the monasteries of Europe. From these latter stocks we have doubtlessly obtained the albinos of the mouse fancy and the scientific laboratory. If the early writers of Asia



THE TURKISH FORT AT TENEDOS CONTAINS MUCH STONE FROM THE MOUSE TEMPLE

FIVE GRANITE COLUMNS AND A MARBLE BASE MAY BE SEEN ALONG THE WHARF.

Minor are speaking of the same species as are the Christian fathers (and they appear to be), then we may say definitely that Apollo's mice were albinos of the species *Mus musculus* and that our laboratory mice are probably descended from the temples of Apollo.

It is quite clear that the mice used in medicinal formulae during the middle ages and to-day are the common house mouse. Yet from this evidence it is impossible to conclude that the sacred mice of the Sminthian cult were of the same species. How are we to know but that the mice of Apollo were field mice, either *Apodemus* or *Microtus*, or the rat *Rattus alexandrinus* or even moles such as *Spalax?* Indeed, this latter creature has a pale coat and is known to the Turks as "Beyaz fare," the white mouse.

Although we may at first thought associate "Beyaz fare" with the white mice having their nest under Apollo's altar, anatomical and behavioristic considerations rule out *Spalax*. The temple mice appeared in both the gray and the white form. *Spalax* of this region is always pale. The sacred mice depicted

upon coins are long tailed, whereas *Spalax* is short tailed. Besides, *Spalax* could never be tamed. Gesner says: "sicut Aeschylus in Sisypho testatur cum ait: Sed agrestis quis est Smintheus." In spite of this statement, the crop destroyer of the Troad, *Microtus*, is excluded on account of its rudimentary tail.

This leaves *Apodemus sylvaticus*, *Rattus alexandrinus* and *Mus musculus*. It is true that all three of these animals could be tamed as were the sacred mice. The fact that one finds no *Rattus alexandrinus* in the Troad to-day proves nothing, because *Rattus rattus* and *Rattus norvegicus* may have both in turn replaced it in this region since classical times. The strongest evidence against it is the fact that it is not easily domesticated. Although *Apodemus sylvaticus* may be tamed with greater ease than *Rattus alexandrinus*, *Mus musculus* more commonly associates itself with men and is much more adaptable to human haunts. I caught in a wheat field near Soma (Asia Minor) a female specimen of *Mus musculus gentilis* which was so tame that it would eat within an inch of my hand two days after its capture.

In the summer of 1930 I visited the island of Tenedos. There I trapped in the town, the old fort, two windmills and a peasant's mud hut. At Tenedos there were collected about 40 specimens, all *Mus musculus!* I took five mice on the adjacent mainland of Keykeli (between Troy and Alexandria Troas), all *Mus musculus!* At Kalloni (Mitylene) near ancient Arisba were procured eight specimens, again all *Mus musculus*. From such samples of the mouse population it is evident that *musculus* is the predominating mouse of the region. If we wish to make sub-varietal distinctions, these were all of the gray-bellied European form, and only far inland from Smyrna did I encounter the light-bellied *gentilis* sub-variety. As grain has always moved from the mainland to the islands and never *vice versa*, one would expect the white-bellied form to be gradually encroaching upon the territory of the European form. Thus gray-bellied *Mus musculus* has probably inhabited this region ever since Trojan times. Curiously enough, the albinos of the scientific laboratory were originally of the gray-bellied European stock, as proven by their conformation and breeding.

According to calculations upon the persistence of Mendelian recessive characters in strains mating at random, it is almost impossible to eliminate such a character as albinism from a wild stock, once it has become firmly established. We may be certain that Apollo's sacred mice, when turned loose in devout homes upon their missions of mercy, contaminated stocks of their own species in the neighborhood of the temple. Thus, albinism would be expected to persist among the mice of the locality in spite of later selection by such enemies as weasels and owls, barring general catastrophe, because gray mice may carry latently the hereditary factor for albinism. Such grays carrying albinism always throw offspring in the ratio of three grays to one albino when mated to other such carriers. This means that perhaps an occasional albino might still be found near the site of Apollo's temple to-day. It should identify for us the species of Apollo's mice. It was not my fortune to capture a white mouse, nor did I inquire concerning them, lest the inhabitants, eager to please, should invent tales for me.

One evening I sat before a coffee house on Tenedos but a stone's throw from the site of the first mouse temple. Half a dozen Greeks and Turks had been chatting with me over the hot cups. During a lull in the conversation I looked out over the blue sea to the visible mainland where I could view the shore of Troy to the left and that of Alexandria Troas to the right, and I dreamed concerning

the prosperous days of that now barren land. My imagination jumped from the sojourn of Menelaus on Tenedos across to the fall of Troy and thence down to Alexandria, where I had recently seen the curious foundation of a palace or a temple. Breaking the silence and startling me, an old wine merchant in the group said off-hand that in the summer of 1929 a white mouse with pink eyes appeared in his house. He used to place food for it until it became fairly tame but never tame enough to be handled. This mouse could have been none other than *Mus musculus* from his description.

Thus it is probable that Apollo's sacred white mice on Tenedos have transmitted albinism for about 2,200 years or 8,800 generations, the longest heredity of a simple variation of which we have written record. Thus the mice of the Sminthian temples used for auguries and the curing of human ills were probably *Mus musculus*, whose present-day descendants, like the industrious one on my desk, swarm our scientific laboratories, even surpassing the traditions of their glorious past by nobly contributing to our knowledge of cancer, tuberculosis and many other diseases and safeguarding our lives with the sacrifice of theirs in the testing of sera.

Note:—I have not considered the remote possibility of a new mutation to albinism, which has never been observed among laboratory mice, so far as I am aware.

THE PUBLIC SQUARE AT TENEDOS IS THE SITE WHERE STOOD THE FIRST TEMPLE TO THE MOUSE GOD, APOLLO

BIOLOGY IN SHAKESPEARE

By Professor D. F. FRASER-HARRIS
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THE term "biology" for our present purpose is used in a very wide sense, for by biology we understand all those sciences which have anything whatever to do with life.

But we shall not enter upon a catalogue of all the plants and animals referred to by Shakespeare, interesting undoubtedly as that study might be made in competent hands, nor shall we discourse on the various diseases alluded to by our and the world's greatest dramatist.

Let us, rather, consider a few allusions to such subjects as have, in our present-day understanding of them, some distinctly physiological or psychological interest.

We might begin with sleep, of which it is certain that in Shakespeare's time there was no physiological theory.

While all physiologists are not even now agreed on what exactly it is that induces that state of the nervous system and of the mind which we call "sleep," yet there is considerable unanimity about the chief cooperating causal factors.

We recognize that the accumulation of certain chemical substances, which we may call "fatigue-poisons," circulating in the blood, coupled with a diminution of the vigor of the circulation through the brain, along with the absence of sensations and of the more strictly intellectual activities, predisposes to sleep. There are, therefore, at least four participating factors which we may call the chemical, the vascular, the sensory and the ideational, respectively.

And, conversely, the absence of fatigue, too much blood in the brain, the presence of sensations and of mental preoccupations are responsible for the corresponding insomnias.

Shakespeare has noticed at least two of these factors in the familiar address to "Sleep" by the king in "Henry IV" (Part II, Act iii, Sc. 1).

How many thousands of my poorest subjects
Are at this hour asleep! O sleep, O gentle sleep,
Nature's soft nurse how have I frightened thee,
That thou no more wilt weigh my eyelids down,
And steep my senses in forgetfulness?
Why rather, sleep, liest thou in smoky cribs
Upon uneasy pallets, stretching thee,
And hush'd with buzzing night-flies to thy slumber,
Than in the perfumed chambers of the great
Under the canopies of costly state,
And lull'd with sounds of sweetest melody?

Wilt thou upon the high and giddy mast
Seal up the ship-boy's eyes and rock his brains
In cradle of the rude imperious surge;
Canst thou, O partial sleep! give thy repose
To the wet sea-boy in an hour so rude,
And in the calmest and most stillest night,
With all appliances and means to boot,
Deny it to a king? Then, happy low, lie down!
Uneasy lies the head that wears a crown.

In this famous soliloquy Shakespeare contrasts the insomnia of the king brought on by the mental factor—the cares of state—with the sound sleep of his fatigued subjects, and especially with the chemically induced slumbers of the tired-out "sea-boy." The sleep of the latter is of that type which even the storm can not disturb, and which is not accompanied by the usual loss of tone of the muscles, for he does not lose his balance or fall from the rigging.

This maintenance of the posture is in contrast with the loss of muscular tone in drunkenness, for, says Hastings, in "Richard III" (iii, 4)—

Like a drunken sailor on a mast,
Ready with every nod to tumble down
Into the fatal bowels of the deep.

It is well known that in certain cases the very deepest type of fatigue-induced sleep is compatible with the maintenance of the posture and equilibrium, as when in the "good old days" postilions feel asleep on horseback and did not roll off, when to-day cross-channel swimmers are found swimming asleep, when persons thoroughly exhausted have walked miles in their sleep, and finally when sentries have slept without falling down.

The same idea of chemically induced sleep is given us in Cymbeline (Act iii, Sc. 6)—"weariness can snore upon the flint when resty Sloth finds the down pillow hard." And this is echoed by these words from Ecclesiastes—"The sleep of a laboring man is sweet" (V. 12).

The mental factor in sleeplessness is well described in "Romeo and Juliet" (ii, 3):

Care keeps his watch in every old man's eye;
And where care lodges, sleep will never lie.

The phrase, "To purge him of that humor that presses him from sleep," which occurs in "A Winter's Tale" (ii, 3), is probably an allusion to what in modern language we should call a toxic source of insomnia. But of course it refers to the very old view of the four "humors" which from the time of Hippocrates were assumed to be the sources of disease—blood, phlegm, yellow bile and black bile.

Sleep, as every one knows, is the great restorer of energy to the nervous system; for prolonged sleeplessness is much more damaging than lack of food. A sleepless animal at the end of three to four days is as miserable as a starved one at the end of ten to fifteen.

This aspect of things is well described in "Macbeth" (ii, 2):

Macbeth does murder sleep! the innocent sleep,
Sleep that knits up the ravell'd sleave of care,
The death of each day's life, sore labour's bath,
Balm of hurt wounds, great Nature's second course,
Chief nourishment in life's feast.

We are given here six different similes to express the same idea.

Sleep is literally a nourisher in that a certain amount of sleep represents a certain amount of food; we are more hungry after four waking hours than after eight to ten hours of sleep.

Puppies deprived of sleep died at the end of five days, although they were taking food; whereas controls, allowed to sleep as much as they wished, but from which food was entirely withheld, survived to the twentieth day. Shakespeare has embodied the substance of this modern knowledge in the passages just quoted.

In sound sleep, the sensory centers are not accessible to impulses from outside, not even to painful impressions; hence it is perfectly true that "He that sleeps feels not the toothache" ("Cymbeline," v, 4).

The power of sleep to banish sorrow in total unconsciousness is well put by Helena in "A Midsummer Night's Dream" (iii, 2):

Sleep, that sometimes shuts up sorrow's eye,
Steal me awhile from mine own company.

Shakespeare, however, shared the popular tendency to regard sleep as closely resembling death. Physiologically this is quite wrong: sleep is, as he himself has told us, the great restorer; in sleep we recuperate, we sleep to wake.

But when he exclaims in "Cymbeline," "Sleep, thou ape of death" (ii, 2), and again, "Shake off this drowsy sleep, death's counterfeit" ("Macbeth," ii, 3), he is in illustrious company, for Shelley wrote, "Death and his brother sleep" (Queen Mab); and Tennyson called sleep, "Death's twin brother."

Any references that Shakespeare makes to the vascular system—to the heart, arteries, veins and blood—must be peculiarly interesting to us, seeing that our great poet was a contemporary of that other illustrious Englishman, Dr. William Harvey, the discoverer of the circulation of the blood. Shakespeare died one week after Harvey gave his first public lecture as Lumleian Lecturer at the College of Physicians on April 16, 1616.

Shakespeare was fourteen years older than Harvey, for he was born in 1564 and Harvey in 1578, so that as Harvey died in 1657 they were contemporaries for 38 years.

But there is not much likelihood of their having met, for Harvey was a student of medicine at Padua from 1598 to 1602, during the very time when Shakespeare in England was at the height of his activity.

Some uncritical writers have assumed that because Shakespeare and Harvey were contemporary, Shakespeare must have known of the new views of the circulation of the blood which were disturbing the anatomists and the medical schools of Europe. But even if the two great men ever met, the young physician was not in the least likely to discuss with his senior, the actor, a quite revolutionary view of a matter of pure physiology.

Harvey did not publish his discovery until 1628, twelve years after Shakespeare was in his grave.

Some critics have thoughtlessly suggested that Shakespeare might have learned of the Harveian doctrines from his son-in-law, Dr. Hall, of Stratford-on-Avon; but Shakespeare's daughter married Dr. Hall as early as 1607, twenty-one years before the celebrated "De Motu" saw the light at Frankfort-on-the-Main. We have no reason to suppose that worthy Dr. Hall was endowed with any transcendental intuitions regarding matters vascular.

From these considerations we should *not* expect Shakespeare to have been acquainted with the true knowledge of the circulation; and as a matter of fact there is not one word in all his writings to suggest that he did know of it.

In this respect at least he is not beyond his age; on the contrary, he reflects it. His vascular physiology is entirely pre-Harveian, in other words, it is Galenical; it is in accord with the views taught in the medical schools of Europe for 1,400 years, the views of Claudius Galen, that great dictator in all matters physiological.

Galen, although resident in Rome, physician first to the Emperor Marcus Aurelius and later to Commodus, and surgeon to the school of gladiators, was of Greek descent. He was born in the Greek colony of Pergamos in Asia Minor about 130 A. D.

Many of his views, as we might suppose, were based on the still older ones of Hippocrates, of Aristotle and of the anatomists of the famous school of medicine at Alexandria at its zenith, about 300 B. C.

At least the names of these two great masters in medicine were known to Shakespeare, for he makes Sir Hugh Evans in the "Merry Wives" say of Dr. Caius (iii, 1)—"He has no more knowledge in Hibbocrates and Galen—and he is a knave besides." Galen is mentioned again along with Hippocrates, in the same play. "What says my Hippocrates? My Galen?" And once more in "Coriolanus" we have the phrase—"The most sovereign prescription in Galen" (ii, 1). Lastly Galen is mentioned along with Paracelsus in "All's Well" (ii, 3) where Parolles refers to "Galen and Paracelsus" as "all the learned and authentic fellows."

This is interesting in that Paracelsus had died only twenty-three years before the date of Shakespeare's birth.

Before Galen's time it was believed

that blood was found in the veins only, that in them it traveled both up and down for the nourishment of the body; and, since the large arteries after death are found to be empty, it was taught that these vessels in life contained not blood but only "vital spirits."

Galen, by tying a living artery in two places and cutting out the ligated piece, showed at once that during life arteries did contain blood.

To appreciate the pre-Harveian physiology we must understand the Galenical doctrine of spirits, which very briefly was: The food, digested in the intestines, was absorbed thence and carried to the liver, where after elaboration it became possessed of "natural spirits." Still as crude blood it passed to the right side of the heart, whence it went up and down the veins in the manner of a tide. In modern language, "natural spirits" were the equivalent of "power of nourishing." Some of this crude or venous blood was supposed to percolate through the septum dividing the right from the left side of the heart. There are, in reality, no pores, but they were not denied until by Vesalius in 1543, and experimentally disproved later by Harvey.

The blood on the left side of the heart was then supposed to be mixed with air drawn into it by the act of breathing.

This air cooled "the innate heat of the heart," and engendered in the now scarlet blood the "vital spirits" which (carried in the bright blood reaching the tissues by the arteries) conferred on these tissues their capacities for performing their functions.

Finally, said Galen, blood plus vital spirits on reaching the brain produced there the third and last order of spirits, "the animal," the distillation of which was supposed to go on in the cavities or ventricles of the brain.

In this sense the brain was a retort or still, where animal spirits were distilled; and it must be in allusion to this that Shakespeare uses the word "a limbeck" or "alembic" (*al ambeq*) the chemical, medieval Arabic word for a retort or still.

Lady Macbeth is speaking—

> . . . his two chamberlains
> Will I with wine and wassail so convince,
> That memory, that warder of the brain,
> Shall be a fume; and the receipt of reason
> A limbeck only.
>
> —*Macbeth*, *i*, 7.

as much as to say, the state of intoxication will convert the brain into a retort which can not perform its wonted function of distilling the spirits.

Cornelius, the doctor in "Cymbeline," speaking of the poison with which the queen is working, says:

> There is no danger in what show of death it
> makes,
> More than the locking up the spirits for a
> time,
> To be more fresh, reviving.

The word "animal," used here for the third order of spirit, does not mean belonging to a beast; it means "pertaining to the soul" or *anima*, the Latin equivalent of the Greek psyche (soul or life); the full Latin expression being "spiritus animalis." These "animal spirits," which survive in our everyday speech, were to Galen what nerve-impulses are to us—the impulses which ascend and descend the nerve-fibers as sensory and motor innervations, respectively.

A good deal of this old physiology is contained in the speech of Meninius Agrippa, the friend of Coriolanus, who makes "the belly" speak as follows:

> True it is, my incorporate friends,
> That I receive the general food at first
> Which you do live upon; and fit it is,
> Because I am the store-house and the shop
> Of the whole body; but if you do remember,
> I send it through the rivers of your blood
> Even to the court, the heart—to the seat o' the
> brain,
> And through the cranks and offices of man;

The strongest nerves and small inferior veins
From me receive that natural competency
Whereby they live.

The physiology of this well-known passage is indeed Galenical, but not all of it is erroneous: the abdomen does receive the food upon which ultimately the whole body subsists; it is sent by the currents—rivers—of blood to the heart, and some of it reaches the brain. But the very phrase, "rivers of your blood," precludes the idea of a circulation, a returning of the same blood. Galen taught an up and down or tide-like flow; Harvey a flow in one direction and a continual returning—they are totally different things.

In the following passage from "Coriolanus" (v, 1) we have again very much the same ideas regarding the functions of the veins:

The veins unfill'd, our blood is cold, and then
We pout upon the morning, are unapt
To give or to forgive; but when we have
stuffed
These pipes and these conveyances of our blood
With wine and feeding, we have suppler souls
Than in our priest-like fasts.

Shakespeare certainly recognizes the preëminence of the heart and its susceptibility to be disturbed by emotional states, as when he makes Macbeth exclaim:

Whose horrid image doth unfix my hair,
And make my seated heart knock at my ribs.
—*Macbeth, i, 3.*

It is an emotional, reflex, pilo-motor effect, and an emotional, reflex cardio-acceleration respectively that are here being described in picturesque but not inaccurate language.

The passage in "Julius Caesar" (ii, 1) in which Brutus declares

You are my true and honourable wife,
As dear to me, as are the ruddy drops
That visit my sad heart.

has actually been taken to prove that Shakespeare not only knew of the circulation but anticipated Harvey in his discovery.

Now this is really carrying things too far; we may charitably excuse it as excess of hero-worship, but it is perilously near to childishness.

It is true that Shakespeare assigns to the heart a preëminence beyond what it was accorded in the Galenical physiology; the notion indeed is ever before him, as when he says:

O England, model to thy inward greatness,
Like little body with a mighty heart.
—*Henry V, Chorus before Act ii.*

He has no doubt whatever that in fainting it is the heart that is at fault, and that bad news in particular can be a cause, for in "Richard III" (iv, 1) Queen Elizabeth says:

Ah, cut my lace asunder,
That my pent heart may have some scope to
beat,
Or else I swoon with this dead killing news.

But another type of fainting, that due to the sight of blood, was quite familiar to him, for we have in "As You Like It" (iv, 3), "Many swoon when they do look on blood." Present-day physiology calls it an inhibitory, sensori-vascular reflex action.

Shakespeare knew perfectly well that fresh air is necessary to revive the fainting person, for we are told (Henry IV, Part II, iv, 4), "Stand from him, give him air, he'll straight be well," another sensori-vascular reflex; but we do not therefore infer from this that Shakespeare had taken out a course of lectures and demonstrations in "first aid"; no, not even although he says in "Measure for Measure" (ii, 4)

So play the foolish throngs with one that
swoons;
Come all to help him, and so stop the air
By which he should revive.

Just as in our everyday parlance the veins come in for more attention than

the arteries, so too in the plays the veins are more frequently referred to. The blueness of the veins is noticed in "Antony and Cleopatra"—"my bluest veins" (ii, 5).

But there is at least one definite allusion to the arteries in "Love's Labor Lost" (iv, 3) where Biron speaks of "the nimble spirits in the arteries." This is clearly a reference to the vital (arterial) spirits of the Galenical physiology: but we are almost compelled to think that Shakespeare regarded the arteries as devoid of blood, which was the pre-Galenical view.

As a matter of fact Shakespeare's physiology of arteries is a little confused, for he makes Hamlet say (Hamlet, i, 4):

> My fate cries out,
> And makes each petty artery in this body
> As hardy as the Nemean lion's nerve.

The expression in King John (iii, 3) —"blood runs tickling up and down the veins," is in perfect agreement with pre-Harveian teaching. Even if the word here should, more appropriately, be "trickling," it would not alter the sense.

Shakespeare associates life with the blood in the veins, as when we read in "King John" (iii, 3), "Whiles warm life plays in that infant's veins," which is clearly an allusion to the very old Biblical and Hippocratic belief that "the blood is the life." Doubtless it was through watching the sacrificial animal die, as its blood ebbed away, that gave rise to this ancient and very natural belief. In the same strain we have in "King John" (v, 7), "The life of all his blood is touched corruptibly."

There is a passage in "Hamlet" (i, 5) which may refer to the veins and even to the valves in them, where Hamlet, speaking of the poison, says, "it courses through the natural gates and alleys of the body."

Shakespeare was acquainted with at least one property of the blood—its odor—known in modern physiology as the "halitus sanguinis"; for in that very remarkable scene in Dunsinane castle, Lady Macbeth, walking in her sleep, is shown trying to wash away the stain of the blood of the murdered king and saying (Macbeth, v, 1), "Here's the smell of the blood still; all the perfumes of Arabia will not sweeten this little hand." She has just asked, "Who would have thought the old man to have had so much blood in him?"

Related both to the circulatory and to the nervous system is the action of alcohol; and much that Shakespeare says about this has quite the modern ring, as, for instance, in the passage in King Henry IV (II, iv, 3) where the effects of "sherris-sack" are described in detail by the fat knight:

> The second property of your excellent sherris is—the warming of the blood which, before cold and settled, left the liver white and pale which is the badge of pusillanimity and cowardice; but the sherris warms it and makes it course from the inwards to the parts extreme.
>
> It illumineth the face which as a beacon gives warning to all the rest of this little kingdom, man, to arm; and then the vital commoners and inland petty spirits muster me all to their captain, the heart.

There is much good physiology here; alcohol, in not-too-large quantity, is a tonic or stimulant to the heart in that it causes it to drive the blood more forcibly into the peripheral vessels, including those of the face. In the phrase, "their captain, the heart," we see Shakespeare once more recognizing the functional preëminence of that organ. We notice, too, the reference to "the spirits."

The value of alcohol as a general stimulant is brought out when the dying Antony exclaims:

> I am dying, Egypt, dying,
> Give me some wine, and let me speak a little.

The notion that the relatively bloodless liver would be pale is not entirely

fantastic. That great gland if washed free of blood does have a pale, grayish hue; and if therefore a blood-filled liver is the physical basis of courage, there is nothing absurd in the idea that a bloodless and therefore pale liver would be related to cowardice.

In "King Lear" (iv, 2) we have Goneril exclaiming, "milk-livered man." The same sort of idea occurs in "Measure for Measure" (iv, 3), where Lucio says, "O pretty Isabella; I am pale at mine heart to see thine eyes so red."

We should compare this with Lady Macbeth's words—"I shame to wear a heart so white" (Macbeth, ii, 2) and with Gratiano's ("Merchant of Venice," i, 1):

> And let my liver rather heat with wine
> Than my heart cool with mortifying groans.

Shapespeare is in no doubt that it is on the brain that alcohol ultimately acts, for he makes Cassio refuse Iago's offer of a stoop of wine in these words:

> Not tonight, good Iago; I have very poor and unhappy brains for drinking; I could well wish courtesy would invent some other custom of entertainment.—*Othello, ii, 3.*

And again; "O that men should put an enemy into their mouths to steal away their brains" (*Ibid*); and once again when Falstaff tells us (Henry IV, Part II, iv, 3):

> A good sherris-sack hath a two-fold operation in it. It ascends me into the brain; drives me there all the foolish and dull and crudy vapors which environ it.

In the "Twelfth Night" we have the three stages of drunkenness described by the clown: Olivia asks, "What's a drunken man like, fool?" Clown: "Like a drowned man, a fool and a madman; one draught above heat makes him a fool, the second mads him, and a third drowns him."

It is literally true that death in alcoholic poisoning occurs through paralysis of the respiratory center with the symptoms, therefore, of asphyxia as from drowning.

The physiology of digestion and of the allied subject of starvation is referred to with marvelous insight. Thus, when Gaunt says in "Richard II" (i, 3)—"Things sweet to taste prove in digestion sour," it is literally true, whether we confine the word "sweet" to sugars or allow it to refer to the two other principal food-stuffs.

The sugars before being finally incorporated into the tissues, it is thought, go through the stage of lactic acid; and milk-sugar in particular is fermented into that acid with the greatest ease.

It is also a fact of biological chemistry that the chief food-stuffs, the proteins, undergo hydrational changes with the formation of amino-acids, and it is these that are absorbed; further the neutral fats, before they are digested, are split up into glycerine and the corresponding fatty acids, the latter being distinctly sour products.

The baneful effect upon digestion of unpleasant emotions—worry, sorrow, etc.—was perfectly well known to Shakespeare, for he makes the Abbess in the "Comedy of Errors" say (v, 1)—"Unquiet meals make ill digestion."

The unraveling of the complete nervous mechanism by which the digestive function is influenced by emotional states for good or ill, has been fully worked out only within quite recent years by the great Russian physiologist, Pavlov.

Pavlov has shown that all pleasant and refining conditions—music, flowers, change of clothes, fine linen, silver, cut glass, etc.—tend to produce that state of good digestion and appetite learnedly called Eupepsia. This is the sort of thing Shakespeare meant when he said: "The sauce to meat is ceremony" ("Macbeth," iii, 4); and in a line or two later,

> Now good digestion wait on appetite,
> And health on both.

One other example of a pleasant emotion promoting a tonic effect for the whole body is in "King Richard III," (v, 2), where Richmond exclaims:

True hope is swift and flies with swallow's wings,
Kings it makes gods, and meaner creatures kings.

This state of mental exhilaration is referred to in "Henry IV" (Part II, iv, 4), when Prince Henry says: "If he be sick with joy, he will recover without physic."

No less full of insight is the description of the biology of starvation: "I sup upon myself, and so shall starve with feeding" (Coriolanus, iv, 2).

What happens in inanition is that the heart and central nervous system are living upon the fat and muscles of the body generally. These "two noble" tissues are literally subsisting upon all the others; and it is, therefore, biologically correct to say that in starvation one feeds upon oneself.

Shakespeare had grasped the biological significance of life as something *sui generis*, something which if quenched can never be revived. This was far from being the clear-cut belief in his day: life as something unique, whether in plant or animal, impossible of being derived from the non-living, was by no means the doctrine of the learned about 1600, nor for two hundred years afterwards. The belief in Abiogenesis, that is life arising from the non-living, was not finally given up until after the work of Pasteur and of Tyndall in the seventies of the last century.

But in that most painful scene in that most painful of plays—"Othello" (v, 2), Shakespeare makes the Moor, on entering the bed-chamber where Desdemona is asleep with a light beside her, thus soliloquize when he has determined to smother her:

Yet she must die, else she'll betray more men;
Put out the light, and then—Put out the light!
If I quench thee, thou flaming minister,
I can again thy former light restore,
Should I repent me—but once put out thy light,
Thou cunning'st pattern of excelling nature,
I know not where is that Promethean heat
That can thy light relume. When I have plucked thy rose
I can not give it vital growth again;
It needs must wither.

Here, it seems to me, Shakespeare is expressing poetically the essential difference between vitality and any manifestation of energy in the world of the non-living.

Shakespeare seems to have been perfectly aware of the breathing test for cases of apparent death; for does not the King in "King Lear" (v, 3) say:

I know when one is dead and when one lives,
She's dead as earth—lend me a looking-glass,
If that her breath will mist or stain the stone,
Why, then she lives.

And Lear uses the feather test, too: "This feather stirs: she lives" (v, 8).

Shakespeare is fully aware of the great value of rest to the living being, for we have the doctor in the same play (Lear, iv, 4) assuring Cordelia that "Our foster-nurse of nature is repose"; and the expression "life-preserving rest" in the "Comedy of Errors" (v, 1) is in fullest accord with the most recent demonstrations in biology: anabolism is the learned term given to the vital processes involved in rest.

With regard to drugs, although Macbeth is made to say—"Throw physic to the dogs; I'll none of it" (v, 3), yet Shakespeare evidently did not despise medicines, for Cymbeline avers, "By medicine life may be prolonged; yet death will seize the doctor too" (Cymbeline, v, 5).

Apropos of drugs, we have in the same play (i, 6) two references to what in some quarters is called "vivisection": they are both by Cornelius, the physician, who, speaking of the queen, says:—

> Those she has
> Will stupify and dull the sense awhile,
> Which first perchance she'll prove on cats and dogs.
> Then afterwards up higher.

And again in Act v, scene 5:

> The Queen, Sir, very often importuned me to temper
> Poisons for her . . . still pretending
> The satisfaction of her knowledge only
> In killing creatures vile, as cats and dogs
> Of no esteem.

In the description of Falstaff's death (Henry V, ii, 3) there is so accurate a picture of the characteristics of impending dissolution—picking at the sheets or floccitatio; the bloodless, pinched features, facies Hippocratica, and the delirium at the close of life that we may be certain that Shakespeare had witnessed not one but several deathbeds.

Sir John Falstaff is represented as dying in Mrs. Quickly's house in Eastcheap; and the account of the death of the fat knight is a remarkable piece of realism, yet not without its dash of humor, for it opens thus:

> Nay, sure, he's not in Hell; he's in Arthur's bosom, if ever man went to Arthur's bosom.

And the whole passage is exactly as a kindly but illiterate woman might have phrased it,—

> for after I saw him fumble with the sheets, and play with flowers and smile upon his fingers' ends, I knew there was but one way; for his nose was as sharp as a pen, and 'a babbled of green fields. "How, now, Sir John?" quoth I; "what man! be of good cheer." So 'a cried out—"God, God, God" three or four times; now I to comfort him, bid him 'a should not think of God; I hoped there was no need to trouble himself with any such thoughts yet; so 'a bade me lay more clothes on his feet, I put my hand into the bed, and felt them, and they were as cold as any stone; then I felt the knees and so upward, and all was as cold as any stone.

Surgery is concerned with wounds, with preventing them becoming poisoned, with the cicatrices left by them, and finally with the setting of bones that have been broken.

First of all, Shakespeare seems to have known of the surgeon's custom of comparing incisions to letters of the alphabet, for in "Antony and Cleopatra" (iv, 7) we read:

> I had a wound here that was like a T,
> But now 'tis made an H.

Of course he knew the domestic use of cobweb in causing blood to clot, for Bottom says ("A Midsummer Night's Dream," iii, 1), "Good master cobweb; if I cut my finger, I shall make bold with you."

A tourniquet is evidently alluded to in "Othello" (v, 1) where Iago calls for a garter to bind Cassio's leg just cut in two, and then exclaims, "O for a chair to bear him easily hence!" wherein once more we get evidences of intelligent "first aid."

The sepsis or festering of wounds was, until Lister's time, a perennial source of worry to the surgeon. In "Richard II" (v, 3) we read:

> This festered joint cut off, the rest rests sound;
> This let alone, will all the rest confound.

which as a surgical maxim could not be bettered to-day.

Shakespeare evidently understood that a wound could be infected, and yet no mischief be visible from the surface, for we have in "Hamlet" (iii, 4):

> It will but skin and film the ulcerous place,
> Whilst rank corruption, mining all within,
> Infects unseen.

Shakespeare seems to have known about one variety of infection, in the sense that moulds or fungi are to blame for it, for he says in "Hamlet" (ii, 4):

> . . . like a mildewed ear
> Blasting his wholesome brother.

At the same time we must not infer that the great dramatist was beyond his time in the matter of supposing that life

could be engendered in decomposing bodies, for Hamlet says (ii, 2):—

> If the sun breeds maggots
> In a dead dog.

He understands that wounds must heal gradually, that what we call the "Vis medicatrix Naturae" has its own rate of working, for, says Iago ("Othello," ii, 3):

> How poor are they that have not patience,
> What wound did ever heal but by degrees?

As a bland application to a raw wound, we have white-of-egg recommended in "King Lear" (iii, 7), where a servant says:

> I'll fetch some flax and whites of eggs
> To apply to his bleeding face.

A wound having been healed, we call the scar "a cicatrix" and so did Shakespeare, for Volumnia in "Coriolanus" (ii, 1) says of Marcius:

> There will be large cicatrices to show the people
> When he shall stand for his place.

It is a familiar experience that old wounds from time to time give some uncomfortable sensations: it may be in allusion to this that Marcius (in "Coriolanus," i, 9) says:

> I have some wounds upon me, and they smart
> To hear themselves remembered.

Finally, it is well known that when two portions of a broken bone are united by what surgeons call "callus," and when this has become ossified, it is of a consistence much denser and therefore much stronger than either of the two portions of the bone that has been fractured: hence says the Archbishop of York in "Henry IV" (Part II, iv, 1):

> If we do now make our atonement well,
> Our peace will, like a broken bone united,
> Grow stronger for the breaking.

As might be expected, the most penetrating and remarkable pronouncements of Shakespeare are those which refer to the brain, the senses and the mind. In Shakespeare's day the various emotions were not all referred to states of excitement in regions of some gray matter of the brain and left there; they were distributed amongst the various viscera.

Even mental processes were not originally thought to have their exclusive seat in the brain, for the ancient Egyptians and later Aristotle believed the mind or soul to reside in the heart.

This view was held, for instance, by Vico in opposition to Descartes as late as the middle of the seventeenth century. Descartes himself placed the soul in the pineal body—a peculiarly unfortunate localization, seeing that the pineal body consists only of some atrophied cells surrounding a few crystals of mineral matter, "brain sand" or dust, and—

> Dust thou art, to dust returneth
> Was not spoken of the soul.

Even Van Helmont, who died in 1644, thought the soul was in the pit of the stomach, the pylorus. Certain very early Greek thinkers had indeed held that the soul was in the diaphragm, obviously because that great muscle of breathing is so accessible to emotional disturbances.

Although Galen regarded the brain as the true seat of the soul or intellect, that did not prevent the various internal organs from being thought of as related in some special way to the passions and emotions. Thus Pistol, in "The Merry Wives" (ii, 1), says that Falstaff loves Ford's wife "with liver burning hot."

The ascription of anger to the spleen has hardly departed from our everyday speech, as when we speak of a "fit of the spleen" or of a "splenetic" man as meaning an angry one.

If he followed any school of thought in respect of the brain versus other seats of the soul, Shakespeare followed that of Galen rather than Aristotle, for he

makes Prince Henry in "King John" say of the King:

> It is too late; the life of all his blood
> Is touched corruptibly, and his pure brain
> (Which some suppose the soul's frail dwelling-place)
> Doth, by the idle comments that it makes,
> Foretell the ending of mortality.

In other words, he will not dogmatize about the brain as the seat of the soul, but he lets us understand that he knows of some who do so regard it. The delirium of the dying is clearly referred to in the last two lines.

Whatever Shakespeare did or did not believe about the cerebral seat of the soul, he was in no doubt at all that what nowadays we call hallucinations are very directly the products of disordered states of the brain.

The best known example of this is the "dagger of the mind," that elusive weapon which Macbeth saw but could not lay hold of ("Macbeth," ii, 1):

> Is this a dagger which I see before me?
> The handle towards my hand. Come! let me clutch thee:
> I have thee not and yet I see thee still,
> Art thou not, fatal vision, sensible to feeling
> As to sight? or art thou but
> A dagger of the mind, a false creation
> Proceeding from the heat-oppressed brain?
> I see thee yet in form as palpable
> As this which now I draw.

We have everything here: the visual hallucination of the dagger—a dagger of the mind—and it is all traced to Macbeth's disordered brain. Even the actual language can not be improved upon after 300 years: it is poetry scientifically justified.

Undoubtedly a visual hallucination is referred to by the queen in "Hamlet" (iii, 4) as the ghost is disappearing:

> This is the very coinage of your brain,
> This bodiless creation ecstasy
> Is very cunning in.

Possibly one of the most remarkable passages of biological import in all the plays is one in "Love's Labour Lost" (iv, 2) where the schoolmaster, Holofernes, speaks of ideas in these words:

> These are begot in the ventricle of memory, nourished in the womb of *pia mater*, and delivered upon the mellowing of occasion.

One of the interesting things about this statement is that it involves two technical terms of anatomy—a "ventricle of the brain" and the "pia mater," the latter, the anatomists' name for the soft, delicate membrane which, closely investing the gray matter of the hemispheres, conveys to it its nutrient blood-vessels.

"The ventricle of memory" was a phrase of the Arabian doctors of medicine, who taught that the brain possessed three cavities or ventricles in which resided the three mental faculties as follow—sensations in the anterior, imagination in the middle, and memory in the posterior one. Those views were adopted by the doctors of theology in the Middle Ages.

Against this particular belief Vesalius inveighed in his celebrated treatise, "De corporis humani fabrica," published in 1543. He wrote: "I wonder at what I read in the Scholastic theologians and the lay philosophers concerning the three ventricles with which they say the brain is supplied." Modern anatomists describe five ventricles.

Here Shakespeare adopts the terminology of the medieval writers; although it is by no means easy to see how he came to have access to it—the man who, when he died, left not a book, not even a second-hand one, behind him.

The phrase "nourished in the womb of pia mater" is, if anything, still more obscure; but this is not the only place in the plays where the membrane is mentioned.

The clown in "Twelfth Night" (i, 5) says:

> Whose skull Jove cram with brains; for here he comes,
> One of thy kin has a most weak pia mater.

And once more it is referred to in "Troilus and Cressida" (ii, 1) where Thersites declares of Ajax, "His pia mater is not worth the ninth part of a sparrow." The pia mater does literally nourish the brain, and therefore, metaphorically, may be said to bring to development anything functionally related to the activity of the brain.

Whether Shakespeare really knew what the pia mater is can not now be determined, but assuming that ideas are "begot" in a cerebral ventricle (which they are not), it would be permissible to regard them as nourished by the membrane that nourishes the organ of thought. The completion of the analogy between giving birth to a child and bringing forth a thought is thus made possible.

Apropos of nourishment of the nervous system, there is an exceedingly striking statement in "Antony and Cleopatra" (iv, 8), where Antony says, "Yet we have a brain that nourishes our nerves."

We have only to translate this into modern physiology to perceive, what is literally true, that the cells of the brain are trophic for, that is, preside over the nourishment or vitality of the nerves. This is precisely what the brain does for the nerves; hence it has been called their "highest trophic realm." But in this sense it is impossible that Shakespeare could have known the facts; not until the microscope revealed that every nerve-fiber proceeds from a nerve-cell, and that, severed from the cell, the fiber dies, could we know all that is implied in this line.

It is, however, more probable that in this passage the poet is using the word "nerves" as meaning tendons in the original sense of nerves (neura).

There is another equally remarkable utterance regarding the nervous system, where Hamlet says (iii, 4):

> Sense, sure, you have,
> Else you could not have motion!

The principle that sensory impressions must precede motor in the education of the nervous system is now-a-days regarded as of immense practical importance. The fact could not possibly have been known to Shakespeare that those tracts in the central nervous system which subserve sensation are functionally developed a considerable time before those which subserve motion. We must regard this as one of those remarkable intuitions into scientific truth of which, at times, the poet's mind gives us such excellent examples.

Apropos of the development of the body, Shakespeare has not failed to note the "breaking" of the voice coincident with puberty in the male. The passage is in the "Merchant of Venice" (iii, 4) where Portia enumerates the various things she will do when she assumes the rôle of a young man; one of them is to

> speak between the change of man and boy,
> With a reed voice.

Physiologically allied to this subject is the effect of castration on the voice: this, as is well known, prevents the male vocal cords lengthening, so that the voice remains boyish and high pitched. Coriolanus (iii, 2) says:

> My throat of war be turn'd
> . . . into a pipe
> Small as a eunuch.

Shakespeare has some particularly penetrating remarks under the heading of the biology of the senses.

With regard to vision, the first phenomenon we might notice is that of the colored "after-image" (as it is technically called) associated with some degree of retinal fatigue. It is where Katherine in "The Taming of the Shrew" (iv, 5) says:

> Pardon, old father, my mistaking eyes,
> That have been so bedazzled with the sun,
> That everything I look on seemeth green.

This experience must be familiar to many; if the eyes are over-stimulated by

exceedingly bright sunshine and one goes suddenly indoors, everything takes on a rather ghastly, pale green color.

The next example has to do with reflections of light from the cornea.

When you look closely into the eye of another person, you see a tiny image of yourself reflected from the convex mirror of the other eye; these images are known in biology as the "Purkinje-Sanson" images. They are clearly referred to in "Troilus and Cressida" (iii, 3), where Achilles says:

> . . . eye to eye opposed,
> Salutes each other with each other's form.

One of the most interesting conditions related to the sense of vision is the trance of Lady Macbeth. It is in the same scene as that in which we found the reference to the smell of blood (v, 1). Lady Macbeth is being watched by the doctor and by a lady-in-waiting, who remarks that she is "fast asleep." The doctor observes, "You see her eyes are open," to which the lady replies, "Ay, but their sense is shut."

Now first of all this is not natural sleep, for in that condition the eyelids are always closed; it is a state allied to somnambulism. In this state, the centers for vision in the brain are inhibited and functionless, so that although the eyes are open, the brain behind them is not perceiving anything, and therefore the individual is psychically blind. The state is akin to that of the mind-blindness induced in the hypnotic trance.

The unpleasant sensation of giddiness is noticed several times in Shakespeare's plays.

"Giddiness" is the name given to the subjective aspect of a disturbance in the sensory apparatus for the appreciation of one's orientation in space; it is the perceptual aspect of impending or actual overthrow of the equilibrium.

There are two varieties of giddiness or vertigo; one when the sufferer is unable to maintain his balance and, feeling faint, falls or tends to fall to the ground —a condition most usually the result of a diminution of the blood supply to the brain.

Since the whole brain—cerebrum and cerebellum—suffers from this anemia, the sensory centers for vision are rendered functionless, in consequence of which the sight fails or, as the patient puts it, "everything goes dark."

This is precisely what King Henry complains of (Henry IV, Part II, iv, 4), "And now my sight fails, and my brain is giddy." Let us note once again that Shakespeare correctly attributes the disability to the organ involved, the brain itself.

A very common cause of interference with the heart which produces anemia of the brain is the reception of bad news, as when King John says (iv, 2), "Thou hast made me giddy with these ill tidings."

The other variety of giddiness is that known as "rotational vertigo," the sort we experienced when, as children, we spun round our vertical axis, suddenly stopped and were for a minute or two exceedingly dizzy, unsteady and perhaps also slightly sick.

In rotational giddiness external objects seem to be moving round in the direction opposite to that towards which the person last turned. This apparent movement of external objects is exactly what is alluded to in "The Taming of the Shrew" (v, 2), "He that is giddy, thinks the world turns round." And lastly we know that if we are giddy, we can correct the giddiness and the illusory movement of the external world by turning round in the opposite direction.

This is precisely what Shakespeare refers to when he makes Benvolio in "Romeo and Juliet" (i, 2) say: "Turn giddy, and be holp by backward turning."

One of the most obvious functions of the brain is the power of speech, so that various imperfections of speech denote disease in one or other region of the organ of the mind.

Complete loss of speech is called aphasia; but, short of this, there is a functional disorder where words can still be spoken, *i.e.*, there is no paralysis, but in which they are all jumbled up so that they make no sense. The technical term for this is "paraphasia." In "A Mid-summer Night's Dream" (v, 1) we have a *perfect* description of paraphasia:

> His speech was like a tangled chain,
> Nothing impaired but all disordered.

I doubt whether any neurologist today could put it more pithily.

We may now close this study of biology in Shakespeare by considering a passage which is surely one of the most striking we have yet examined. It occurs in "Hamlet" (i, 5) that play, according to some critics, the profoundest of them all; it is where the ghost remarks:

> The glow-worm shows the matin to be near,
> And 'gins to pale his uneffectual fire.

Each of these two lines embodies a deep biological truth. First of all, why does the glow-worm show the matin to be near?

Because the feeble light of the glow-worm, in common with all other lights, begins to appear paler as the dawning daylight increases in intensity. The relatively feeble light emitted by the glow-worm can be seen easily in the dark because the retina, being, as it is called, "dark-adapted," responds readily to very slight illumination; as Pericles (ii, 3) says:

> like a glow-worm in the night
> The which hath fire in darkness, none in light.

In a strong light we do not perceive feeble lights; we do not see the stars in the daytime, although some of them are there; the moon in the daytime is just visible; in strong sunlight it is so difficult to perceive the flame of a fire that many people firmly believe that the sun is putting the fire out.

A candle, quite useful at night, scarcely adds anything to the illumination of a room in the daytime, as indeed Shakespeare says: "We waste our lights in vain, like lamps in day."

This is only an example of a particular case of a principle of wide-spread occurrence in living matter; namely, that a tissue, for instance the retina, having been stimulated and being in a state of activity, is insensitive to or irresponsive to further stimulation, an incapacity which has been called "functional" or "physiological inertia." If the retina is already stimulated by the daylight, it will not respond to (perceive) any much feebler light, such as that of a glow-worm.

Shakespeare, in fact, has said as much in "Romeo and Juliet" (i, 2), "One fire burns out another's burning."

But still more interesting is the use here of the word "uneffectual." Why is the light of the glow-worm an uneffectual fire? Because it is light without heat; a light that can not set fire to anything is indeed uneffectual. The light of a glow-worm is a perfectly cold light. When we pick up a glow-worm, it does not burn our fingers in the least. It has lately been ascertained that the light emitted by this creature (Lampyris) is due to an oxidative process known as chemi-luminescence whereby chemical energy is transformed into light without having to pass through the intermediate stage of heat. Man has not yet contrived to produce light without heat. Nature did so long, long ago when the light of the first glow-worms and the fire-flies twinkled in the primeval forest, when the first Noctiluca blazed their trail in

the dark ocean, as the glistening wave struck the shore of that world millions of years ago.

Light without heat—without wasted heat—is what man ardently desires to have, and may some day discover, but up to now has not been able to produce.

The spectrum of this animal light also shows it to be devoid of vibrations both towards the red and towards the violet end: light such as this without the violet or the ultra-violet rays must be chemically inert, non-actinic and therefore once more "*un*effectual." We may well conclude with this splendid example of the amazing insight into living nature which our and the world's greatest poet possessed.

While one must deprecate anything like uncritical hero-worship, and while we should not yield to the not very uncommon temptation of reading into certain passages a meaning which it is quite impossible Shakespeare could ever have intended, yet we shall not greatly err if we admit that in the writings of this extraordinary man we find a wealth of observation in the realm of living things which is as extensive as it is penetrating and which is absolutely unparalleled in the literature of any other country.

The more we understand of what "the myriad-minded" Shakespeare has observed, the more we become lost in astonishment at the universality of his genius. Well did Pope say of him, "Shakespeare seems to have known the world by intuition, and to have looked through Nature at one glance."

THE MENTALITY OF PRIMATES

By Professor LESLIE A. WHITE
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In chapter three of "The Descent of Man," Charles Darwin writes, "My object in this chapter is to show that there is no fundamental difference between man and the higher mammals in their mental faculties." Essentially the same position is taken to-day by prominent sociologists and social psychologists. For example, Professor F. H. Hankins, comparing apes with men in his "An Introduction to the Study of Society" (New York, 1928) states, "In spite of his large brain, it cannot be said that man has any mental traits that are peculiar to him. His superiority is one of degree, and particularly in the higher degree of abstract thought, constructive imagination, analysis and generalization which he possesses." (p. 56). And, again (on p. 327): "All of these human superiorities are merely relative or differences of degree . . . . ."

The thesis of this paper is that, while there are many and impressive similarities between man and ape, there is one fundamental difference and this difference is one of kind, not of degree.

That apes do behave like human beings in many striking ways has been amply demonstrated by many students since Darwin. They give human-like expression to fear, rage, jealousy and love. They play games and jokes and even seem to express, quite eloquently at times, that highly prized virtue, gratitude. But, in spite of these many likenesses, there is one kind of behavior which is not manifested by any animal save man, and that is the use of symbols. And, I repeat, this difference is one of kind, not of degree. An animal is either capable of using symbols, or he is not; there are no intermediate stages.

One reason why discussions of mental differences between apes and man have been so muddled is because such hopelessly inadequate terms as *reason, think, intelligence* are used. The old problem, "Can dogs reason?" well illustrates the impassé into which such terminology leads us. One must use concepts that can be defined objectively. Human beings use symbols; apes do not. It remains for us, then, to define the concept *symbol* precisely and in objective terms.

Tool-using Capacity

Before discussing symbols, however, I should like to discuss another capacity which distinguishes primates from other animals, namely, the ability to use tools. I do not wish to go so far as to say that primates alone among animals use tools; I have heard of elephants wielding branches or sticks with their trunks. But certainly, the primates alone are distinguished for their ability to use tools and to build according to freely conceived plans. It is true that beavers, birds and wasps build. But they do not build according to freely conceived plans. The structures accomplished by these creatures are built according to plans which, specifically, constitute a part of their respective hereditary equipments. But apes[1] can build according to plans which are formulated to fit the situation of the moment. Thus an ape can build a structure of boxes and, with a tool which he has made by joining two sticks, knock a banana from the roof of his cage. The building activities of beavers, birds and wasps do not vary beyond narrow and rigid limits. But the ape can adapt his building activities

[1] I am referring chiefly to chimpanzees.

to any situation; moreover, he can devise tools appropriate to the occasion.

The difference between the tool-using and the building capacities of apes and other animals, then, lies in this: The behavior patterns of the non-primates are hereditary equipment of limited scope; the tool and building patterns of apes are not inherited, but are devised freely and for a great range of situations. The ape has the capacity to conceive of configurations and then to project them into materials, tools and objectives. He has the capacity to execute a series of acts implicity before he commences them overtly. Figuratively speaking, he rehearses in his mind the series of steps necessary to attain an objective before he makes a move. Then he proceeds to re-arrange his environment according to his plan. Thus the ape is a sub-lingual architect, or, even a dramatist. To say that he accomplishes his feats of building by trial and error is absurd. It is true that apes, like men, make trials and commit errors. But this does not mean that out of a mass of random movements a plan is born. The ape has the plan to begin with; the trials and errors are simply the incidents of his attempt to realize it in action. If this were not true the ape would be as likely to try to stand on his bowl of water as a packing-box to reach a banana, and as likely to try to poke it down with a gunny-sack as a stick.

Capacity to Use Symbols

We see, then, that primates differ from non-primates in the manufacture and use of tools and in the capacity to build. We now turn our attention to the capacity which distinguishes man from the other primates as well as from other animals, birds and insects. This is the capacity to use symbols. A symbol is a datum—a sound, an act or a material object—the meaning of which is arbitrarily assigned to it by those using the symbol. It differs in this respect from all other things. The meaning of anything is simply its position in its context. The meaning of a non-symbolic datum is determined by the properties which inhere in the datum itself and by the inherent properties of its context. Thus, the meaning of a canoe paddle, for example, is determined by the shape and properties of the wood and by its relation to a person, a canoe and the water. We are now in a position to distinguish between the symbolic behavior of human beings and the non-symbolic behavior of other animals.

Man, bird and beast communicate with sounds. But there is a fundamental difference between the vocal utterances of birds and beasts and the language of man. The meaning of infra-human cries is determined in the phonetic elements themselves and in the organisms of the creatures using them. But the meaning of a word, a phonetic element or compound, does not inhere in the sounds themselves; they are assigned to them by the users. Thus, the phonetic compound *si* has no meaning in itself; it may refer to the act of the eye, a great body of water, an affirmative reply or something else. The meaning has been assigned to this sound-compound in purely arbitrary fashion. But the cries of birds and animals are different. When a mother hen sounds a warning to her chicks, the meaning inheres in the sounds themselves and in the organisms of the chickens. The situation is slightly different when animals are taught to respond to words. Here the meaning of the sounds are not inherited by the animal, but nevertheless the meaning still inheres in the very sounds themselves. In short, cries are *signs* to birds and animals, not symbols, whether they be learned or inherited.

The same is true of acts and material objects. The meaning of an act or a material object to an infra-human creature is determined wholly by the properties of the act or the object itself and

its relation to its context. But this is not always true where human beings are concerned. A stone is simply a stone to an animal or a bird, but to a man it may be the repository of a spirit. "Those aren't just sticks," a Pueblo Indian once told me very emphatically, when we were discussing prayer-sticks. And indeed they weren't. They looked like "just sticks" to the uninitiated, but they were sacred symbols to the Indian. Why? Because meaning had been created by the human organism and arbitrarily assigned to them.

And the same is true of many acts. Raising the right hand when taking an oath has no meaning whatsoever in the act itself; the meaning has been assigned to it.

Three Types of Mental Behavior

We are now in a position to outline three types of mind as manifested by organic life. And it is important to insist upon the qualitative differences between them. Due perhaps to the dominating influence of the idea of gradual evolution, many scholars have sought to interpret stages in mental development as differences of degrees. But certainly differences of kind are abundant enough in organic life: a quadruped either lays eggs or hatches them within the body. An animal breathes with gills or with lungs. And so, in the evolution of mind (which, after all, is simply a function of the organism, just as metabolism, respiration and reproduction are) we have definite breaks, or, more accurately, different types of organization of behavior which are qualitatively different from each other. These three types of mind, then, constitute stages of evolutionary development. Let us now turn to an examination of them.

The Unilinear Type

This is the first stage. In its simplest form, the behavior pattern of the organism is a straight line; the animal approaches or withdraws from a stimulus. In more complex manifestations of this type of mind both stimuli and responses are multiplied, but the *quality of the behavior remains the same;* there is a unilinear relationship between organism and stimulus. Thus, when a dog is separated from a piece of meat by a fence and he runs away from the meat to go through a gate, he is simply responding successively to two different stimuli. This type of mind is the non-tool-using type and embraces all infra-primate creatures.

The Geometric Type

This is the tool-using type of mind and is represented by primates only. Here we have a bi-linear configuration; that is, a relationship between primate and tool on the one hand, and a relationship between tool and objective on the other. Both exist and function simultaneously in the mind of the primate. This means that the primate can create configurations imaginatively, configurations which are in no way determined by heredity, and having created the configurations he can project them into acts and materials. In short, he can make tools and build. I call this type of mind the geometric type because it deals in geometric quantities—both plane and solid—lines, mass, and motion. None of the infra-primate creatures can behave in this manner.

The Algebraic Type

This is the third and most recent stage in the evolution of mind. It is represented by man alone. It consists in the manipulation of symbols. In one respect it is like the geometric type: it consists of bi-linear configurations, the imaginative creation of configurations and their subsequent projection in sounds, acts and materials. But it differs in one respect from the geometric

type, namely, in the sources of the meaning of their respective data. The meaning of data of the geometric type inheres in the properties of the data themselves: the meaning of a hammer or needle, a stick or a stone inheres in the object itself, just as the meaning of a right-angle or a circle inheres in the configuration. But the meaning of a symbol, like the meaning of an algebraic quantity, is assigned to it, in purely arbitrary fashion: X may equal ten horses or three quarts of milk or anything else. This type of mental organization, like the unilinear and the geometric, may be complicated by the multiplication of items involved in any given situation, until one manipulates symbols with symbols. In every-day language, we call this "abstract thinking," but the essential quality of the behavior remains the same. All linguistic thinking is abstraction.

Organic evolution has, then, produced three great types of mind, or mental organization, the first including all non-primate organisms, the second primates only, and the third man alone.

The Significance of the Mental Capacities of Primates

Infra-primates perform; primates create as well. Beavers go on building dams generation after generation, ants repeat their social life with each succession of progeny. But with primates we get creative ability; the ape is the world's first artist. But the ape does not preserve his works, nor does he talk about them. Man does both. Civilization may be defined as the accumulated products of man's tool and symbol capacities; the former gives us the material side of civilization and the latter the intellectual and spiritual.

Postscript: Professor Edward Sapir, who kindly read this article in manuscript, suggests the terms *reactive*, *instrumental* and *symbolic* for the types of mind which I have called *unilinear*, *geometric* and *algebraic*, respectively. While I am preserving the original terms because of the emphasis which they place upon the configurative aspect of mind, I feel that Professor Sapir's terms should be placed at the disposal of the reader.—L. A. W.

SCIENCE SERVICE RADIO TALKS

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THE PIPES OF PAN, OLD AND NEW[1]

By Dr. DAYTON C. MILLER

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For many years we have been studying the flute both historically and scientifically, and in doing this a collection of instruments illustrating all types of flutes has been acquired, now numbering more than a thousand specimens. Several of these have been selected for demonstration, representing the older types and also the most modern.

The flute is probably the first musical instrument used by man; it antedates history, and there are many legends and myths regarding the origin; "its infancy was passed in the twilight of fable." For our purposes the flute may be defined as any mouth-blown musical wind-instrument, in which the sound originates in the vibrations of the jet of air.

The earliest form of flute is a simple, natural piece of bamboo, a few inches long, which may be open throughout its length or may be closed at one end by the natural septum. When one blows across the open end of such a tube, a musical tone is produced. The edge of the tube may be blunt, or may be bevelled to a sharp edge. The primitive flutist soon discovered that tubes, or pipes, of different lengths give tones of different pitches, and so he tied several pipes together, side by side, and produced what is now called by the rather poetic name, the Pipes of Pan or Syrinx. This is probably the instrument referred to in Genesis, called in Hebrew, "Ugab," and translated in the English version as "organ." The poetic and romantic legends of ancient writers, and of modern artists, are fanciful, and need not be repeated now. The early Pan-pipes had a variable number of tubes—usually three, five or seven—tuned in a more or less capricious manner. This type of instrument is so simple in construction, so "cheap" to manufacture, and withal so musical in its effects, that it survives at the present time. Pan-pipes are in very common use by the natives of the islands of the sea, in Australia, Africa, and even for modern music they are used in the rural districts of central Europe and Italy. They are made in various sizes, corresponding to soprano, contralto, tenor, bass and sub-bass parts. The melody instruments may have as many as twenty-eight pipes, all tuned, varying in length from one and one half to ten inches. The instruments used for harmony usually have only one octave of tuned pipes, though other pipes may be added merely for appearance. The largest pipes may be three feet or even five feet in length. They are used in bands, consisting of from twenty to forty performers, and produce music which has the effect of a pipe organ. Such a band of twenty-two instruments is in my collection.

It was probably a very early discovery that a simple pipe, accidentally having a hole in the side of the tube, would give two tones, depending upon whether the hole is open or closed, and that the pitch of one of the tones depends upon the position of the hole. Thus there developed the very common type of wind-instrument consisting of a single tube, with a larger or smaller number of

[1] Primitive and modern flutes were played by Professor Miller during his talk to demonstrate their tonal qualities.

finger-holes, from which a scale of musical tones may be obtained. For simple melodic music, the number of holes required in the tube can be controlled by the fingers directly.

The Pan-pipes are sounded by simply blowing from the mouth across the open end of the pipe, and this method survives to-day in the flutes used in classical Japanese and Chinese music. It was another prehistoric discovery that the pipe may be sounded by blowing across a hole in the side of the tube. A third method was early developed, of providing the tube with an artificial mouth and lips arranged to direct a jet of air against the edge of the sound-hole, as in the common whistle.

These whistle flutes were very widely used from the twelfth to the eighteenth centuries. They were made in various sizes, from a few inches to eight feet or more in length, and were played in quartets and in larger choirs or bands, sometimes consisting of forty performers. This type of flute gives a very soft and simple tone, which may be described as mellow or sweet. The French call it the *Flûte douce*, and the Italians refer to it as the *Flauto Dolce*, and in general it is known as the flute-a-bec or the English flute, as distinguished from the German flute to be described later. In England this whistle type of flute is known as the Recorder.

Pepys' (1632–1703) Diary (1688) contains this entry:

> To Drumbleby's and there did talk a great deal about pipes, and did buy a recorder, which I do intend to learn to play on, the sound of it being of all sounds in the world most pleasing to me.

Shakespeare (1564–1616) introduces a band of Recorders in "Hamlet." Hamlet says:

> *Ham.* O, the recorders! Let me see one (turning to Guildenstern . . .) Will you play upon this pipe?
> *Guild.* My lord, I can not.
> *Ham.* I pray you.
> *Guild.* Believe me, I can not.
> *Ham.* I do beseech you.
> *Guild.* I know no touch of it, my lord.
> *Ham.* It is as easy as lying; govern these ventages with your fingers and thumb, give it breath with your mouth, and it will discourse most eloquent music. Look you, these are the stops.

The whistle flutes are restricted in range by the fact that the mouthpiece is simply a hole in a block of wood and is inflexible. Though the tone is sweet, it lacks variety, and soon palls on one. An instrument maker of London, about a hundred years ago, stimulated for a time the waning interest in the whistle type of flute by introducing the so-called English flageolet. He made instruments with two, and even with three, body-tubes attached to one head, so that one performer could play to a very limited degree music of two or three parts, simple duets and trios.

The type of flute blown crosswise directly from the mouth, over a hole in the side of the tube, has been known for two thousand years or more; the strength and quality of tone can be varied, and it is much more effective than flutes of the whistle type. However, it became a real musical instrument only about two hundred and fifty years ago, when the first key was added, so that a complete musical scale became possible. This kind of flute, known as the transverse or German flute, was held in very high esteem, being the most popular of all musical instruments for more than a century, beginning about 1700, when it became one of the principal instruments of the orchestra.

As music grew in complexity, additional holes in the sounding tubes were required and these were controlled by a key mechanism which sometimes is very complicated. Some flutes have as many as eighteen keys. There then developed the necessity for more accurate intonation and more uniform quality of tone; this led to the modern concert flute, which is usually constructed upon the acoustic and scientific principles developed about eighty years ago by Theobald Boehm, of Munich. The Boehm

system flute probably approaches more nearly to the scientific ideal than any other musical instrument. It is *par excellence* the instrument for the enthusiastic lover of chamber music, while it retains its prominent position in the orchestra. The musical literature for the flute is greater than for any other solo instrument, excepting only the violin.

Flutes of different sizes and made of different materials give certain variations in tone quality which have not yet been fully appreciated. A richness of tone and an expressiveness have been acquired which are very pleasing. Unfortunately, the flute being the most agile of solo instruments, its ability to render rapid and difficult note-combinations is often exploited at the expense of its tonal characteristics.

LIQUID HELIUM

By Dr. H. C. DICKINSON

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THE production of liquid helium in the low temperature laboratory of the National Bureau of Standards in Washington affords an opportunity for a brief account of why the production of very low temperatures is important, what we may hope to accomplish with them, and perhaps for correcting some rather common misunderstandings about them. The name "fixed gas" was used at an early date to designate those gases which had never been obtained in liquid form. As time went on, the list of fixed gases continually became smaller as one after another was liquefied. Although chlorine and hydrochloric acid gas probably had been liquefied in 1804–6, it was not until in 1823, when the great pioneer scientist Michael Faraday accidentally liquefied chlorine gas, that a systematic study of the properties of gases was begun. Faraday promptly sensed the meaning of his discovery and thus began the studies which led to our present knowledge of gases. Faraday himself succeeded in producing liquid hydrogen sulphide, carbon dioxide, nitrous oxide (laughing gas), cyanogen, ammonia and hydrochloric acid gas.

This knowledge has made possible the entire industry supplying us with ice, ice cream and cold storage products, as well as our widely advertised gas and electric household refrigerators. In all these processes a gas is first compressed to the required pressure, then cooled until it becomes a liquid. This liquid is then allowed to evaporate at a lower pressure and thus produce cold.

Along about 1870, the list of known gases which had not been liquefied, and which were therefore called permanent gases, had been reduced to six. Early attempts to liquefy these more difficult gases such as air and hydrogen did not succeed because scientists did not know enough about the nature of the problem. It was well known that high pressures and low temperatures were needed to reduce gases to the liquid state, but other essentials were unknown, or at least unrecognized. Soon it was discovered, however, as we know to-day, that for each gas there is a "critical temperature," above which it can not be liquefied by any amount of pressure, but below which liquid will be formed if the pressure is high enough.

The more difficult gases, such as air, hydrogen and helium, have critical temperatures so low that they can not be reached by ordinary methods of refrigeration, so the gases do not liquefy when compressed. But a new fact about gases was discovered which met this difficulty. All gases when compressed and sufficiently cooled become colder when allowed to escape or expand through a

nozzle or valve. This fact permits the regenerative refrigerating system which is now generally used to liquefy gases. The gas is first compressed to a high pressure, then cooled by any convenient means to as low a temperature as necessary, and allowed to expand through a small orifice. This cold gas is then used to further cool the compressed gas which follows it. The colder compressed gas is still further cooled on expansion and the process goes on, the temperature going lower and lower, until finally liquid is formed. Other methods also are used for making liquid air in large quantities, but this is the process by which the more difficult gases are liquefied.

Of the more difficult gases, air is easiest to liquefy. This liquid was first produced in measurable quantity in 1883. Hydrogen comes next and was first made in 1898; liquid helium, however, is a vastly different matter. It was first produced by Professor H. Kammerlingh Onnes at Leiden, Holland. This Dutch professor and scientist was the dean of all gas liquefiers. In the very early days, about 1890, he started the great low temperature or cryogenic laboratory at Leiden. For some forty years he devoted most of his great energy to researches in the field of very low temperatures. His descriptions of the difficulties and disappointments of his early work are intensely interesting. After years of careful study and preparation in which all the less difficult gases were liquefied many times the first liquid helium in the world was made in 1908. Professor Kammerlingh Onnes died in 1926, but Professors Keesom and de Haas, his successors, carry on the work. I saw and photographed a small tube of liquid helium in their laboratory last summer. It was surrounded first by a vessel of liquid hydrogen and outside that by a flask of liquid air.

Now helium itself is not a common substance. Most of the world's supply is found in the United States, and it is collected from a few natural gases which contain only a small percentage of helium. As you all know, it is the lightest gas except hydrogen. It is used for military airships because it is totally nonburnable and safe. It is by far the most difficult gas to liquefy because its boiling point, $-452°$ F., is much lower than that of any other gas. The temperature means little, however, until one calculates that it is only about 7.6° F. above absolute zero, the lowest possible temperature. Compared with this the temperature of liquid hydrogen is 36.7° F. and that of liquid oxygen 162° F. above the absolute zero. The liquid helium produced at the Bureau of Standards recently was further cooled to 3.4° F. absolute by lowering the pressure with a vacuum pump. The very lowest temperature ever produced was reached in a similar way after months of preparation by Professor Kemmerlingh Onnes and was about 1.6° F. absolute.

The process of liquefying helium is a complicated one on which the staff of the bureau has been working for many months. First cold brine is used to cool carbon dioxide and to precool air. The carbon dioxide is then used to cool and liquefy air, the liquid air is then further cooled by reducing the pressure and used to cool and liquefy hydrogen. The pressure on the liquid hydrogen is then lowered to a point where the hydrogen begins to freeze. This very cold hydrogen is then used to cool the compressed helium which on expanding further cools itself and finally becomes liquid at a temperature of 7.6° F. absolute.

From 1908 to 1923 liquid helium was available only at the University of Leiden. In 1923 it was liquefied at the University of Toronto, Canada, by Professor McLennan; in 1925 at the Physikalische Technische Reichsanstalt, Berlin, Germany, by Professor Dr. Meissner; at the University of Berlin in 1930

by Professor Ruhemann; and finally at the Bureau of Standards on April 3 by Dr. F. G. Brickwedde and his staff, Mr. Cook, engineer, Mr. Scott, junior physicist, Mr. Smoot, mechanician, and other assistants.

But why produce liquid helium? In the first place, we have at present an international temperature scale which is uniform throughout the world, but has not been extended to the lowest temperatures, and liquid helium will assist in making this extension possible.

Beyond this, however, you have all heard much of Professor Einstein and perhaps something of other scientists now working on the very difficult subject of the constitution of matter and of the universe. This modern attempt to push back the confines of human knowledge has already vitally affected the industries and our every day life through such things as the radio, x-rays, television and numerous others. However, some of the most difficult questions raised by these researches can be answered only by resort to the study of phenomena at the temperatures made possible by liquid helium.

There is now available at the Bureau of Standards in Washington a laboratory where some of those interested in such problems as are here mentioned can find the answers.

DID PREHISTORIC MEN LIVE IN THE MIDDLE WEST?

By Dr. M. M. LEIGHTON

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JUST a few weeks ago, a very important and a very unusual conference was held in Chicago, under the auspices of the National Research Council. This conference brought together a distinguished group of highway and construction engineers, railroad officials, state geologists, noted anthropologists and heads of sand and gravel companies, from all parts of the Middle West.

What do you think they talked about? Was it engineering problems? The best ways to build railroads, highways, buildings? Not at all! They talked about prehistoric man and what should be done in an effort to discover either his remains or some evidence of his having lived in this region thousands and thousands of years ago. Recent scientific discoveries, in Europe and Asia especially, have proved definitely that man's life on the earth dates back as much as a *million* years, but not on this continent.

In the past, possible discoveries have been made in this country—discoveries that might have furnished scientists with the proof that they needed to settle the question, but the finds were rendered valueless by their removal when found. Such discoveries should not even be touched until trained scientists have given them their study and formed professional opinions on the spot.

Sometime, somewhere in the Middle West, some one is apt to make an important discovery during the course of some commercial excavation, and the men who attended the conference in Chicago want that discovery to be made under conditions that will give it the scientific endorsement that it will certainly deserve.

During recent years, the search for the bones of our earliest ancestors has caught the popular interest, and most of us read with enthusiasm the newspaper and magazine accounts of the ambitious expeditions that are led by Roy Chapman Andrews, and other famous explorers.

You will recall that most of these

"hunters after truth" conduct their searches in southern Europe, or in western Asia and Asia Minor, or in northern Africa. There is a reason for this. Anthropologists are generally agreed that the first humans lifted their eyes from the ground and stood erect beneath the clear skies of the Mediterranean region. It is practically certain that mankind's birthplace was within 2,000 miles of the plains of Syria, which as you know lie at the eastern end of the Mediterranean Sea. As I say, authorities agree on that point, but there is wide difference of opinion among them in regard to the direction from Syria of that all-important locality. Each expedition is based on careful research and well-supported opinions whether it plunges into the African wastes, treks across the desolate plateaus of southwestern Asia, labors under the scorching sun of Arabia, Mesopotomia and Persia, or carries on its investigations under more pleasant conditions in Europe. No one can yet say that *his* idea has proved to be the correct one. But hope persists eternal.

From this native district, wherever it may have been, the first race of humans spread slowly across the face of the earth, along four main lines of migration. One group apparently struck out to the southeast and developed into the Australoid race. Another group migrated to the south—the ancestors of the Negroid race. A third group, fortunately, decided to shift to the northwest and in time developed into the Caucasian or white race. The fourth group, for some reason or other, was attracted by the ever-receding horizon to the northeast, and they moved in that direction, to become the ancestors of the Mongoloid race.

As successive generations of these groups migrated farther and farther from the unknown central locality they became more and more affected by varying conditions of climate, natural resources, food supplies and living habits, so that in time each group became differentiated from the others in respect to color of skin, features of the face, stature, relative mentality and cultural achievements. Before long, the four major races of mankind were very clearly and distinctly demarked.

Now to get back to the question of whether or not prehistoric man ever lived in the Middle West. All the evidence seems to point to the fact that man very probably did not originate in the new world, but that he migrated from Asia, by way of Siberia and Alaska. But when did this migration take place, and to what human level had these first Americans developed when they first set foot upon the North American mainland?

We know that prehistoric men lived in western Europe and in eastern Asia long before the last epoch of the Great Ice Age. Since the climatic changes which caused the ice invasions were world-wide in their influence, and the ice invasions took place in North America and Europe at the same time, the glacial deposits and the human records that they may contain both in Europe and America, can be correlated on a fairly exact time basis. Why shouldn't we find evidence of glacial man in this country? Surely, the American Indians, the Mayas, the Aztecs and the Incas were not created as the white man found them. They must have developed from some common ancestral form, and that development must have been going on for thousands of years before the white man arrived, so great were the racial and even tribal differences by that time.

Did the ancestors of these native Americans get here before the last great ice invasion; did they arrive during the time of the ice invasion itself; or did they get here after the great glaciers had melted away? Only time and careful search of the various glacial deposits can clear up the mystery. These depos-

its cover most of the surface of Wisconsin, Minnesota, Michigan, Illinois, Indiana, Ohio, northern Missouri, Iowa, northeastern Kansas, eastern Nebraska, and areas to the north, northwest, and northeast.

We are entirely justified in projecting the possible existence of the first Americans back as far as the closing stages of the last glacial epoch, and to say that they may have witnessed the spectacle of a great ice sheet. If that was the case, some proof of their existence at that time should be preserved in the glacial drift deposits of the Middle West. There are some people who believe that the extinct race which we refer to as the Mound Builders were a very ancient race of people. This group flourished in the Middle West possibly as much as 5,000 years ago, probably no earlier. They were, beyond question, descended from more primitive stock, which may or may not have preceded them in this region. We must look back thousands of years beyond the first days of the Mound Builders, if we are to solve the mystery of the original Americans.

How about the cliff-dwellers of the Southwest? Will their records solve the riddle? No, I am afraid not. Old as are the ruins of their once populous communities, they date back no earlier than 500 or 600 to 2,000 or 2,500 B. C.—only a fraction of the time that has elapsed since the Great Ice Age. Then, too, we must take into account the fact that the skulls of both the Mound Builders and the early cliff-dwellers show that these people belonged to the species *homo sapiens,* as does modern man himself. They were distinctly not members of an earlier, more primitive prehistoric race such as the early Ice Age men belonged to. Every now and then some one finds some fossils in North or South America, and advertises them as the remains of an ancestral man or even anthropoid. But in each case, so far, their claims have been shown to be false or insecurely founded or debatable, and the hunt is still as hot as ever.

In the last analysis, the whole question of the antiquity of man in America must be answered by an appeal to geology. With what geologic formations are the oldest remains of man or man-made implements associated?

So far, no positive evidence has been unearthed to show that humans existed hereabouts during Glacial times. Any relics, in order to be satisfactorily dated, must be found in association with glacial deposits or related deposits. If we do find them below glacial deposits that have not been disturbed since they were laid down, then we can be sure that the relics are older than the materials that have buried them. It is equally safe to apply the same line of reasoning to the explanation of any discovery showing that man lived here during the time that the glacial materials were being deposited.

We can be greatly encouraged by some findings which seem to be almost authoritative, as, for example, the recent discovery in Oklahoma of a man-made flint spear point, which was found lying with the bones of primitive elephants, horses, camels and smaller animals—all of which creatures are believed to have become extinct on this continent during the Great Ice Age, or shortly after its close. We can say definitely that some form of mankind lived here before the extinction of these forms of animal life which were abundant during the Ice Age, but which are not known to have lived very long beyond that period, and there is reason for thinking that migrants of the Mongolian race may have crossed the Bering Strait before the close of the Glacial Period, long enough ago for them to populate extensively the western hemisphere before Columbian days.

HOW A SPIDER CAUGHT AND DINED UPON A SIX-INCH SNAKE

By L. F. PINKUS

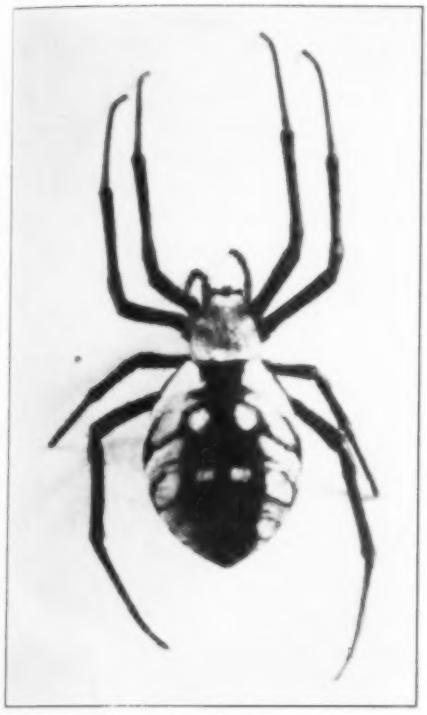
CENTRAL HIGH SCHOOL, ST. LOUIS, MO.

If one were to study the menus of various centuries and races one would obtain an extremely interesting result. It was not only Lucius Lucinus Lucullus, who died 57 B. C., that devised splendid meals. Even some members of our animal world seem to have quite a Lucullan appetite at times. This part of natural history has interested quite a number of our great naturalists. Darwin, Fabre and others owe some of their intimate knowledge to their great inquisitiveness concerning the dinner plates of our little foes and friends.

I myself recently had the rare opportunity of getting a glimpse of an unusual bill of fare of our well-known yellow-black garden spider, *Miranda aurantia*. Lucas, in 1833, according to Anthony Comstock's "Spider Book," gave this beautiful creature the name Miranda from the Latin word meaning "to gaze upon," "to wonder," and *aurantia* meaning "golden" (Fig. 1).

That spiders like what seems to us unusual foods for them has been attested by various observers. In his "American Spiders and their Spinning-work" (1889), Henry McCook relates a story of a farmer who found a bird, the kingster, entangled in the snare of such a spider. Another case occurred near Philadelphia, where a David DeHaven found a humming bird being captured in a spider's web. The observer watched the process of swathing the poor victim until it was completely wrapped around, when he slew the spider and rescued the bird, too late, however, for it was quite dead. Several instances of spiders as fishermen and hunters are related by Professor E. W. Gudger in *Natural History*, Vol. xxv, No. 3, from which work I quote the following account of S. Cummings:

> On the evening of the 13th inst. a gentleman in this village [Batavia, N. Y.] found in his wine cellar a *live striped snake*, nine inches long, suspended between two shelves by the tail, by spiders' web. The snake hung so that his head could not reach the shelf below him by about an inch; and several large spiders were then upon him, sucking his juices. The shelves were about two feet apart; and the lower one was just below the bottom of a cellar window through which the snake probably passed into it. From the shelf above it there was a web in the shape of an inverted cone, eight or ten inches in diameter at the top and concentrated to a focus, about six or eight inches from the under side of this shelf. From this focus there was a strong cord made of the multiplied threads of the spiders' web, apparently as large as common sewing silk; and by this cord the snake was suspended.
>
> Upon a critical examination through a magnifying glass, the following curious facts appeared. The mouth of the snake was fast tied up, by a great number of threads wound around it so tight that he could not run out his tongue. His tail was tied in a knot, so as to leave a small loop or ring through which the cord was fastened; and the end of the tail, above the loop, to the length of something over half an inch, was lashed fast to the cord to keep it from slipping. As the snake hung, the length of the cord from his tail to the focus to which it was fastened was about six inches; and a little above the tail there was observed a round ball about the size of a pea. Upon inspection this appeared to be a green fly, around which the cord had been wound as the windlass with which the snake had been hauled up; and a great number of threads were fastened to the cord above, and to the rolling side of this ball to keep it from unwinding and letting the snake down. The cord, therefore, must have been extended from the focus of the web to the shelf below, where the snake was lying when first captured; and, being made fast to the loop in his tail, the fly was carried and fastened about midway, to the side of the cord. And then, by



—*Photographed from life by L. F. Pinkus*

FIG. 1. A LIVE FEMALE *MIRANDA AURANTIA*

THE "WONDERFUL GOLDEN" SPIDER, SEEN FROM ABOVE.

—*After McCook, from Beecher*

FIG. 2. A SNAKE SNARED IN A SPIDER'S WEB.

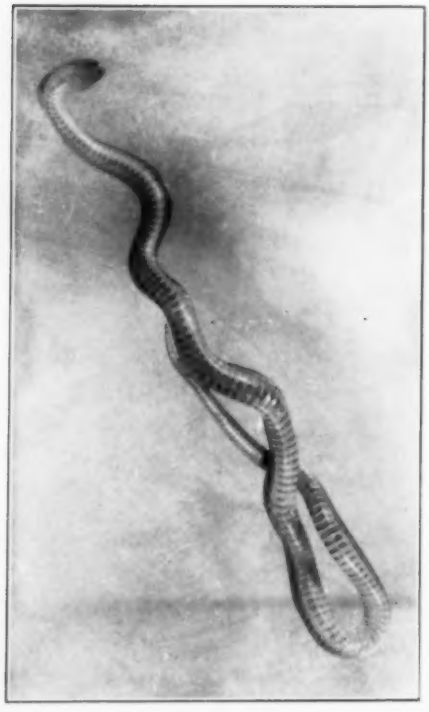
rolling this fly over and over, it wound the cord around it, both from above and below, until the snake was raised to the proper height and then was fastened as before mentioned (Fig. 2).

In this situation the suffering snake hung, alive, and furnished a continued feast for several large spiders, until Saturday forenoon, the 16th, when some persons, by playing with him broke the web above the focus so as to let part of his body rest upon the shelf below. In this situation he lingered, the spiders taking no notice of him, until Thursday last, eight days after he was discovered, when some large ants were found devouring his dead body.

—*Photographed from life by L. F. Pinkus*

FIG. 3. VENTRAL VIEW OF THE "WONDERFUL GOLDEN" SPIDER.

A very similar account, differing only in details, was given in the same journal by D. Lyman Beecher. Dr. Asa Fitch has likewise published an account of such a phenomenon in the *Annual of Scientific Discovery*, 1862, pp. 334–35. In this case, however, it was a question of but one spider, not of several as was the case in the two preceding experiences, suspending the snake by the head, not by the tail. The odd thing about these observations was the slow torture



—*Photograph of a preserved specimen by L. F. Pinkus*

FIG. 4. A YOUNG 6-INCH SNAKE, *TROIDOCLONIUM LINEATUM.*

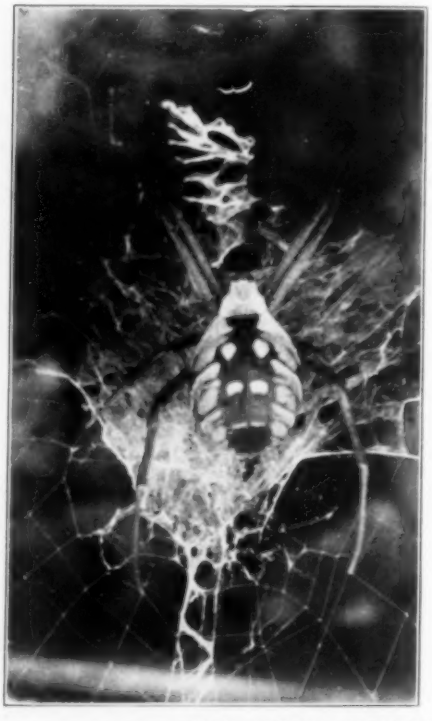
lasting over a period of days. Just what spiders were responsible is not known.

Let me now add my little story of how the Miranda, the "wonderful" spider, caught and dined on a snake (Fig. 3).

In order to make the instruction of natural history for the city pupils as vivid as possible I keep a few live pets of various kinds in the laboratory. The boys also occasionally bring in specimens. One day, a pupil brought in a lined-snake (*Tropidoclonium lineatum*), a mother with a brood of young ones. After having proudly exhibited his trophy for a few days in a cage I had provided, he took his booty home, but overlooked a little snake about six inches long, which he unwittingly left in the cage (Fig. 4). The following day I used this cage as a home for a full-grown female "*Miranda aurantia.*" It was a few hours later that we noticed that the place was already occupied. Rather strange room-mates, the spider and the snake, although both are despised members of the animal world. And here the strange drama begins.

The yellow-black lady made herself quite at home and during the first night of her stay manufactured one of her beautiful art pieces, placing her web diagonally across the cage (Fig. 5). The two occupants lived together in peace for a few days in the same quarters, apparently not minding each other, and were fed by the pupils or by myself.

One fine morning I entered the laboratory and found the members of the class very excited. Stepping up to the cage where they had gathered, I noticed the snake lying on the floor of the cage quite changed, as one may see from the accompanying picture (Fig. 6). The



—*Photograph by L. F. Pinkus*

FIG. 5. THE "WONDERFUL GOLDEN" SPIDER IN THE CENTER OF HER WEB.

spider was sitting in her web, which was as lovely as ever. Immediately thirty youngsters bombarded me with questions; for the excitement was intense as the numerous conjectures as to what had happened were being hotly defended and as ardently denied by the youthful observers. The questions hurled at me, I could not fully answer at the time.

After a while one of the laboratory attendants gave us the explanation. The previous day after we had left the room, he happened to come to the place and was not a little surprised to find that the snake was caught with the tail-end in the spider web. The astonishing thing was that the reptile, in spite of frantic efforts, could not free itself from the web. The busy arachne wrapped her ribbon-like threads around the snake more and more. She seemed to make use of the situation to her advantage because while the snake was doubling up, the spider tied the victim up in such a way that the snake could not straighten out again. After a while the snake seemed to be overcome by the poison from the bites of the spider. Soon after that, the spider hoisted her prey to the center of the web and dined on the snake in her fashion. When she had finished she cast out the remains, leaving us the specimen in the shape as the picture illustrates (Fig. 6). Then she rebuilt her web.

It will be seen that the entire process of enveloping the snake, and particularly of extracting the juices, lasted but a short time. This is at variance with the accounts mentioned in the early part of this paper, but is entirely in accord with both the observations and the experiments made by Dr. Ernest Warren, Director of the Natal Museum. He found that the South African spider he dealt with had captured a lizard and had eaten practically all of it within two and a half hours. In describing the feeding process and the action of the digestive

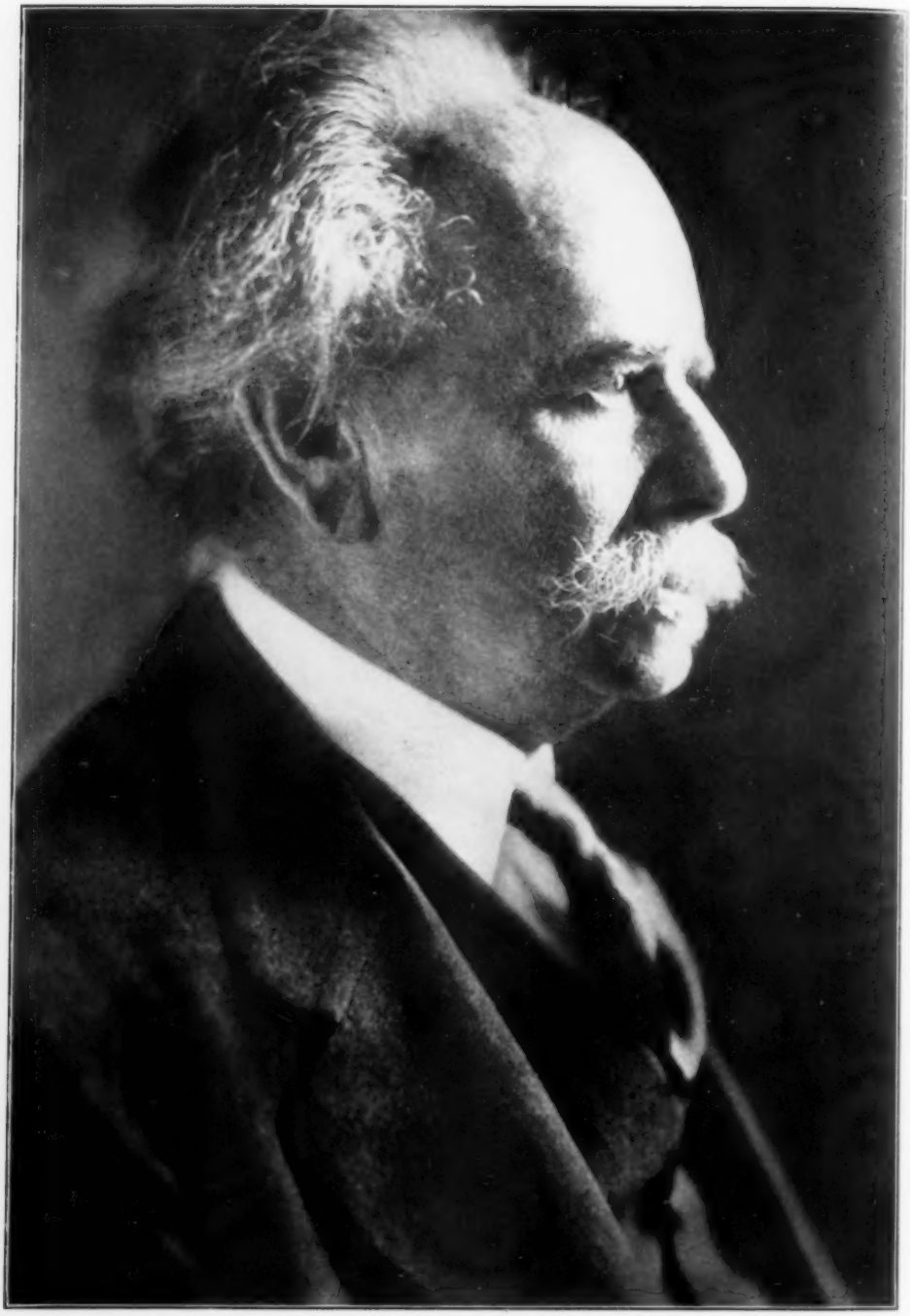
—*Photograph by L. E. Pinkus*

FIG. 6. THE REMAINS OF THE LITTLE SNAKE
AFTER THE SPIDER HAD DINED ON IT.

fluid upon the flesh of the lizard, he says, "In the course of an hour the whole body of the lizard, with head, limbs and tail, had been kneaded into a round, wet mass permeated with the digestive fluid and continuously being chewed by the chelicerae." "After a period of about two and a half hours the body (about $1\frac{3}{4}$ inch long) of the lizard had been reduced to a small, blackish, rounded and somewhat dry mass about $\frac{1}{4}$ inch in diameter. This mass the spider allowed to drop to the ground."

One wonders if the poet Southey was aware of such strange happenings when he addressed the following lines "To a Spider":

For, Spider, thou art like the poet poor,
Whom thou hast help'd in song.
Both busily, our needful food to win,
We work, as Nature taught, with ceaseless pains,
Thy bowels thou dost spin,
I spin my brain.



DR. FRANZ BOAS

PROFESSOR OF ANTHROPOLOGY, COLUMBIA UNIVERSITY; PRESIDENT OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

THE PROGRESS OF SCIENCE

THE NEW ORLEANS MEETING OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

After twenty-five years the American Association for the Advancement of Science returns to New Orleans for its winter meeting, to be held from December 28 through January 2. Once again Tulane University is the host institution.

New Orleans, with its mild winter—like a northern Indian summer—will, it is hoped, enable delegates to appreciate the wealth of interesting setting in this unique area of the United States.

Though it has grown to be a cosmopolitan city of half a million, New Orleans still offers a startling contrast between a modern commercial metropolis and a historical section whose French and Italian inhabitants suggest Europe rather than twentieth century America. The Vieux Carré, which is to be the ground for sightseeing trips by all sections of the association, has many buildings still standing which date from the days of the French and Spanish occupations.

Professional historians and amateur sightseers alike will visit such places as the Cabildo, or government house of the Spanish era, where the transfer of the Louisiana Purchase to the United States by France took place; the Old Absinthe House, where the French pirates of the Gulf plotted; the St. Louis Cathedral, one of the oldest religious edifices in North America; the antique stores of the Rue Royale. Just outside the city is the battlefield of Chalmette, scene of the Battle of New Orleans, in the War of 1812, the colonial mansion used as a headquarters by General Andrew Jackson is preserved as a memorial. Accessible by motor bus are the adjoining country districts, where archaic French is still heard as often as English, and

TULANE UNIVERSITY AND ITS SURROUNDINGS

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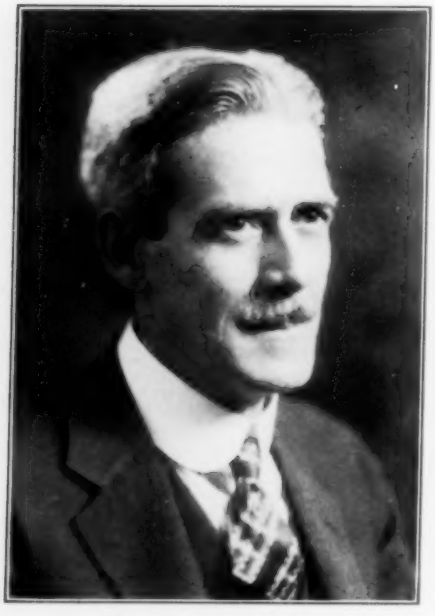

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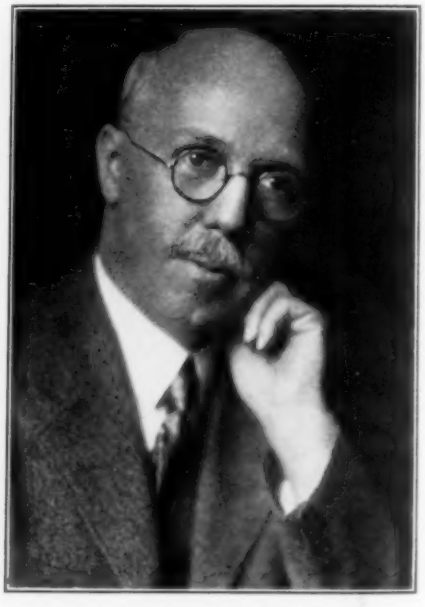

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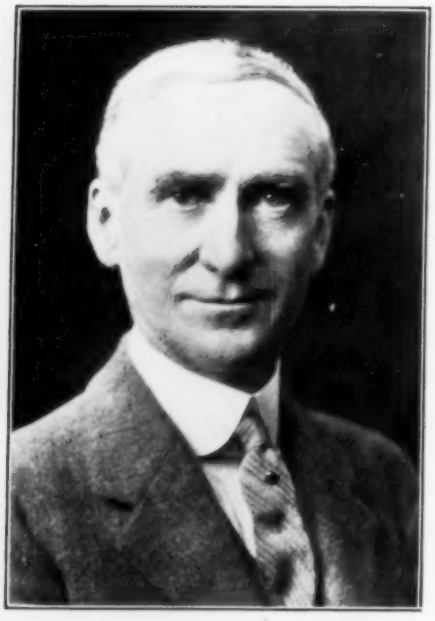

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DR. HOWARD T. KARSNER

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THE MUNICIPAL AUDITORIUM

HEADQUARTERS OF THE GENERAL LECTURES AND THE RESEARCH EXHIBITS

it is here that are found those descendants of the Acadians whose story was so eloquently told in Longfellow's "Evangeline."

Contrasting with such an atmosphere is the new $2,000,000 municipal auditorium which the city has graciously placed at the disposal of the association for its larger gatherings. Contrasting, too, are the city's 1,200 factories and the miles of shipping—New Orleans has one of the largest water-fronts in the world—which bear witness to its position as the gateway to Latin America.

The 92-acre campus on which are located the main departments of Tulane University is in the heart of New Orleans' most exclusive residential section, facing the beautiful Audubon Park. Thanks to the able administration of President Albert B. Dinwiddie, the host institution offers the visiting scientists a whole series of new facilities which will be of great value in carrying on the work of the convention. The most important of these is the new Hutchinson Memorial Building, used for the instruction of third and fourth year students in the college that has made Tulane nationally known in the field of medical science. It is located on Tulane Avenue, opposite the great Charity Hospital, the facilities of which are used in instruction. This building with equipment cost approximately $1,250,000 and is in every way one of the most modern units in the United States for the study of medicine.

Since much of the time of the engineering section is to be given to Mississippi River flood control problems, the new laboratory equipment in hydraulics which is one of the latest additions to the college of engineering will be of especial importance. This is located in the old Engineering Building, which also houses the school of civil engineering. The new Science Building, housing the Museum of Middle American Research, will also be of special interest. It is to be the scene of several meetings of the archeological section. Another group of buildings which is to be utilized is the H. Sophie

PROFESSOR C. G. WILLIAMS

DIRECTOR OF THE OHIO AGRICULTURAL EXPERIMENT STATION; CHAIRMAN FOR AGRICULTURE

DR. ERNEST HORN

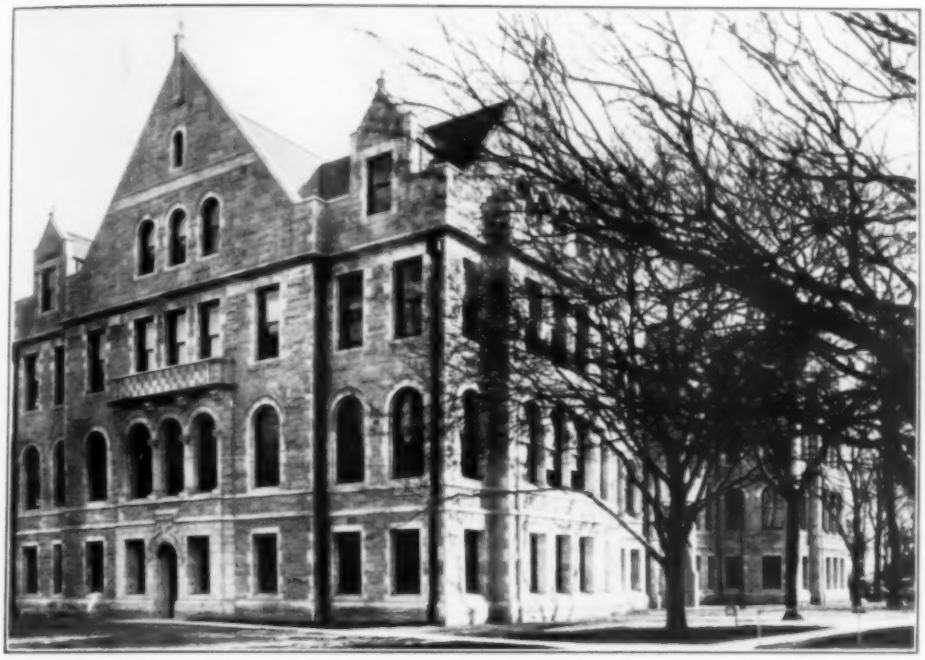
PROFESSOR OF EDUCATION, UNIVERSITY OF IOWA; CHAIRMAN OF THE SECTION OF EDUCATION

DR. A. B. DINWIDDIE

PRESIDENT OF TULANE UNIVERSITY; HONORARY CHAIRMAN FOR THE NEW ORLEANS MEETING

DR. D. S. ELLIOTT

PROFESSOR OF PHYSICS, TULANE UNIVERSITY; CHAIRMAN FOR THE NEW ORLEANS MEETING



THE SCIENCE BUILDING

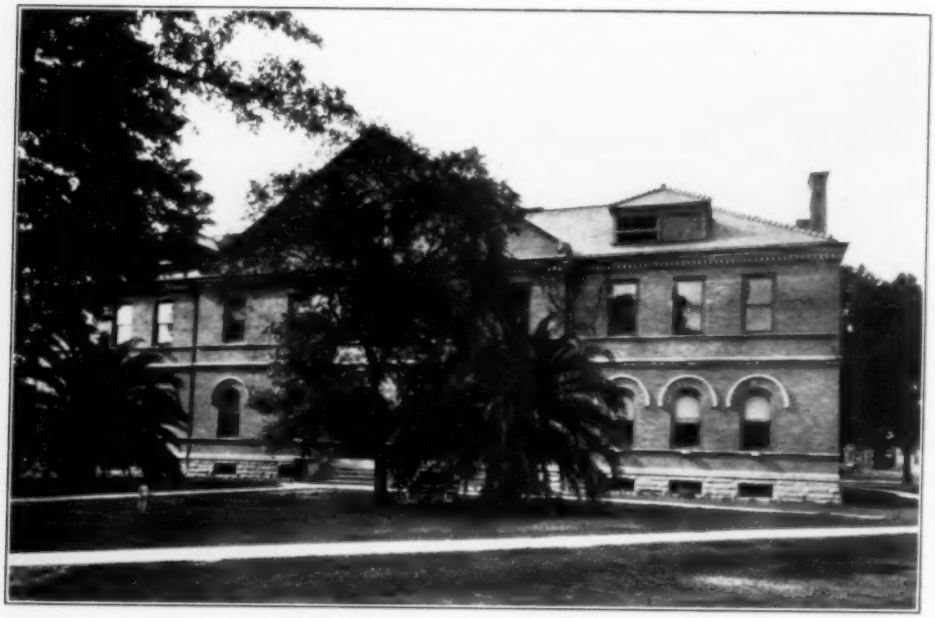
Newcomb College for Women, a division of the university which has its own campus. The dormitory buildings and Dixon Hall, the auditorium of Newcomb College, are to be used by the mathematical section.

In accordance with the objectives of the American Association for the Advancement of Science, the program will carry out the dual function of bringing together scientific men and their researches on the one hand and at the same time of promoting a better appreciation of scientific aims and accomplishments by the public.

Five popular lectures, each of which is to deal with some phase of social, physical or biological science presented in a non-technical manner, will form the main portion of the part of the program for the public. These are to be presented on five successive nights at the municipal auditorium. In addition, an exhibit of scientific apparatus and methods is to be open to the public during the convention period.

The program will be found rich in the purely technical features which are still the main activities of the association. Besides the general sectional meetings which will take in all members under the group headings, twenty-six affiliated societies have announced their intention of meeting with the association. Also to be mentioned is the gathering of the Southern Society for Philosophy and Psychology which is meeting with the national group this year. There are many joint meetings and cross-section sessions on related and borderline subjects.

The varied program contains much material that will appeal to the non-specialist. A meeting has been arranged to commemorate Edison and his work. There are a number of symposia scheduled which are of more than ordinary interest. Professor Franz Boas, president of the association, leads a two-day



THE PHYSICS BUILDING

THE RICHARDSON MEMORIAL MEDICAL BUILDING

A TULANE UNIVERSITY CAMPUS SCENE

symposium on "Growth," and three sections of the association join in a discussion of "Social and Economic Institutions of the Mayas." Among the addresses will be the ninth annual Josiah Willard Gibbs lecture by Professor P. W. Bridgman, of Harvard University, on "Statistical Mechanics and the Second Law of Thermodynamics," and one by Professor S. J. Holmes, of the University of California, on "The Changing Biological Effects of Interracial Competition." Professor Richard P. Strong, of the Harvard Medical School, will give an address on some aspects of tropical medicine; Professor Irving Fisher, of Yale University, lectures on "First Principles of Booms and Depressions."

And so, between December 28 and January 2, the Crescent City, with its green golf courses in mid-winter and its interesting outdoor diversions, once more becomes the national focus of scientific interest, while the American Association for the Advancement of Science meets as the guest of Tulane University and the City of New Orleans.

J. H. H.

OTHNIEL CHARLES MARSH

THE CENTENARY OF OTHNIEL CHARLES MARSH

At the recent meeting of the National Academy of Sciences, at Yale University, very proper recognition was made of the centenary of one of America's most famous men of science, Othniel Charles Marsh.

Marsh was born on October 29, 1831, at Lockport, New York. He was educated in the schools of Lockport and the Wilson Collegiate Institute, at Wilson, New York, in surroundings replete with minerals and fossils, which in turn gave the initial trend to his tastes and stimulated his lifelong passion for collecting everything that could possibly be of interest in nature and in art. Marsh's further training was at Phillips Academy, at Andover, where he prepared for Yale. Graduating from Yale College in 1860, he spent the next two years in graduate work at the Sheffield Scientific School, followed by three years of study abroad, at Berlin, Heidelberg and Breslau, where he came in contact with some of the master minds of scientific Europe. With this educational background, Marsh was ready to fill the first chair of paleontology ever established, which he did with eminence, from 1866 until his death in 1899. Marsh's work, however, was not professorial in the pedagogical sense; rather was he a collector and investigator whose researches had a far higher educational value—due to their world-wide appeal—than is often true of direct classroom instruction.

The material enumerated in Marsh's deed of gift, when on January first, 1898, he presented his collections to Yale University, included the following: vertebrate fossils, fossil footprints, invertebrate fossils, recent osteology, American archeology and ethnology and minerals, and shows the range of objects which his acquisitiveness prompted him to secure. Beside these there were fossil plants, and, in his residence, which together with its contents was later willed to Yale, there were paintings, and numerous examples of Japanese and other forms of art, as well as a rare collection of living orchids and the very extensive series of trees and shrubs which beautified his estate.

It was largely through Marsh's influence that his uncle, George Peabody, founded and endowed the Peabody Museum of Natural History at Yale, in 1866. One great aim of Marsh's career was the completion of the museum edifice, only the northern wing of which he lived to see, and which, at the time of his death, was so crowded with treasures that when, years afterward, they were moved into the present much larger building, the more than 600 vanloads of material completely filled it as well.

Marsh's principal interests lay in the three higher classes of vertebrates, as he published comparatively little on either fishes or amphibians, although his collections of these are rich, especially in the former group. Of reptiles, his chief concern lay with the dinosaurs, and it is a matter of profound regret that he never completed his study of the group, especially in its philosophical aspect for which his comprehensive knowledge so ably fitted him. His "*Dinosaurs of North America*" (1896) served to clarify greatly the existing knowledge of the anatomy, not only in part but in whole, of this diversified group. Marsh had planned no fewer than 27 monographs, but two of which he lived to complete. Of these the principal ones were to be on the Sauropoda, Stegosauria, Theropoda, Ornithopoda and Ceratopsia among the reptiles, as well as one on the fossil footprints and one on the toothed birds. Of the mammals he proposed to treat the Mesozoic mammals, Dinocerata, and Brontotheridae, as well as the evolution of the brain, and other subjects. Two quartos, the Ceratopsia and the Titanotheres (Brontotheridae), have been com-

pleted by his successors. In preparation for this stupendous work not only were the large collections made, both by his own means and through aid from government funds, but much in the way of preliminary description, illustrated by beautiful woodcuts which were later to form the text figures of the several volumes, was published in the *American Journal of Science*. There were also prepared a large number of lithographic plates in anticipation of future publication, and these are models of precision and execution. Marsh's aim in collecting was twofold, first to determine the geological horizon of each locality where a large series of vertebrate fossils was found, for he hoped to extend their utility as horizon markers, which had not, until that time at least, been recognized, and second, to secure from these localities large collections of the more important forms, sufficiently extensive to reveal, if possible, the life histories of each.

Even though the completion of the task he set for himself was beyond the powers of any one man and thus fell far short of attainment, nevertheless, what Marsh did accomplish and what will yet be learned from the unstudied part of his collections will add greatly to the sum of the world's scientific knowledge.

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